John Eyre Morgan.
Christmas 1897.
From Father.

PRACTICAL PHOTOMETRY.

# PRACTICAL PHOTOMETRY:

## A GUIDE TO THE STUDY

OF THE

# MEASUREMENT OF LIGHT.

BY

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WITH NUMEROUS ILLUSTRATIONS.

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# INTRODUCTION.

THE increasing commercial and scientific importance of the art of Photometry has frequently been brought under the Author's notice by applications for reference to some standard text-book, in which could be found a comprehensive account of the various methods in daily use, as well as a guide to the many precautions necessary to ensure accurate results from the work.

The prevailing uncertainty as to the standard of light cannot long be maintained ; and, when a change does take place, many will be the inquiries for a concise description of the new method. The Author has, therefore, had no hesitation to give a full narration of the various systems now before the public, in order that the future student need not be at a loss where to look for a guide when he finds the familiar methods to which he has been

accustomed swept away. In like manner, the present chaotic condition of the Photometer itself is a fruitful source of much uncertainty. The student is taught to work with one instrument; and is then suddenly called upon to make tests of a responsible character with another which, perchance, he has never seen before, and the description of which he can by no means obtain. To take another case—a photometrist, who has always been solely accustomed to test the horizontal rays in the usual way, is asked to test a burner which instead of throwing its rays horizontally, sends them downwards at all angles, after the manner of the now common recuperative class of gas-burners. On turning to the chapter dealing with "Radial Photometers," he will find a complete account of the work hitherto done in this direction, and of the various instruments invented for the express purpose of overcoming his difficulty, which will no longer be a difficulty to him. Should a newly-appointed and possibly somewhat nervously constituted Gas Examiner find his results of a startling character, let him turn to the chapter on the adjustment of a Gas-Testing Photometer, and something will have to be so far wrong as to require the attention of the maker, if he is not out of his difficulties in a very short time, and ready to defend his

results as correct. On one point, however, he must be certain of his own work, and that is the testing of the meter. No amount of instruction, written or verbal, can make up for neglect in this matter. Should a photometrist be called upon to test the illuminating power of an arc-electric light, and find himself in trouble with the readings, in consequence of the colour of the standard being different to that of the electric light, let him turn to the chapter on "Discs and Disc-Holders," and he will see a ready means out of his difficulty. To take only one more instance out of many—should he be in want of a method for estimating the colour and intensity of the illumination of fabrics, solutions, surfaces, &c., let him turn to the chapter on "Colour Photometry," and he may find relief from his anxiety. In short, the Author has striven to make the work worthy of its title, and *practical* above all things.

As a relief from the hard work of a life largely spent amongst photometers of a utilitarian character, the Author has found much interest in making an examination of some of the methods employed in Stellar Photometry—*i.e.*, the Photometry of the stars. In the course of some work on that question, it occurred to him it would be of interest to determine the actual intensity of the stars in terms of our English unit of light—the average sperm candle; and for

this purpose he has arranged a system which appears sufficiently promising to place it amongst the records. Perhaps some apology is, however, due to the reader for drawing his attention to a tentative proposal. It was originally hoped that sufficient work would have been done in this direction to warrant its being embodied in the chapter; but the prevailing unsuitable weather for stellar observations during the past winter has prevented a sufficiently checked series of observations being made, especially as the work had to be done in such intervals as could be spared for the purpose. However, the system of a standard series of coloured stars of known intensity now introduced for the first time, may not be deemed unworthy of notice in such a work as the present; and the Author presents it to his readers in the hope that they may derive as much pleasure from it as he has had already in devising it.

It would not be right to conclude these remarks without a sincere expression of thanks to those who have kindly assisted in the production of the work, by their permission to use extracts and illustrations. First amongst these, the Author has to acknowledge his indebtedness to Mr. William Sugg, Assoc. Inst. C.E., &c., who has so liberally placed his large experience at the

Author's disposal, and who has materially contributed to the embellishment of the work by the loan of numerous blocks. Mr. Sugg also most kindly entered into the Author's plans for a chromatic standard for Stellar Photometry, and from his designs made the standard illustrated on p. 169. To Mr. A. Vernon Harcourt, F.R.S., Dr. Pole, F.R.S., Captain Abney, F.R.S., Mr. Chaney, Mr. Lovibond, Messrs. Alexander Wright and Co., and others, sincere thanks are also due, and are hereby most respectfully tendered.

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# HISTORY OF PHOTOMETRY.

## CHAPTER I.

THE History of Photometry, like that of other branches of Science, presents a record of unbroken exertion. Various are the methods which have been employed during a period of nearly two hundred years — commencing with François Marie's obscuration method in 1700, when he employed pieces of glass in succession, until he obliterated the light, and then judged of its value by the number required. It is curious to note that even so late as 1875 this system found an advocate in Otto Shuette, who, however, varied it by using tissue paper instead of glass. In 1735 Celcius noted the distance at which small objects became invisible. Twenty-five years later Bouguer made the great step of using discs of tissue paper as the indicator of equal luminosity. Although as originally used the method would at the present day be considered clumsy, yet it deserves careful record as the first approach to the disc system now so universally employed. This experimenter states that Huyghens used

a tube with varying apertures, using the illumination of the interior of the tube as the index. In 1792 Count Rumford introduced his system of comparing the shadows of a rod thrown upon a screen. It is one of the curiosities of literature that this method is almost the only one referred to in various elementary text-books which touch upon Photometry. Although it has certain advantages. the method is one which few practical photometrists of the present day would venture to adopt.

The immortal Herschel did not deem this science beneath the notice of his grand intellect. In 1800 we find that he constructed an instrument to enable him to determine the amount of light lost by reflection from, or transmission through various substances. The principle of his method appears to have been the comparison of the illumination of two surfaces of white paper. Accum evidently met with some difficulty with candles in 1815; and attempted to overcome that arising from snuffing by inclining them at an angle of 30°. In other respects his system was similar to that of Rumford.

Ritchie's Photometer was introduced in 1826. This method consisted in noticing the illumination of tissue paper by lights reflected from two surfaces of white paper inclined at right angles to each other. This arrangement was modified by Yvon in 1872, and by Keates in 1878; and was used by Sugg, with the addition of reflectors, in his travelling Photometer for his experiments on the electric light and high-power gas-burners, which came into such prominence for street illumination about 1880. The celebrated electrician Wheatstone used a small bright ball, which he caused to rotate rapidly round a disc. The two sides of the ball were

thus illuminated by the opposing lights; and their intensity was judged by the brilliancy of the two halves of the curve so formed. In 1833, Arago used a system depending upon the reflection from inclined plates. Some ten years subsequently Bunsen proposed his method of employing a disc of paper having a greased spot in the centre, which to this day is in constant use with but slight variations. Had Bunsen been unknown in other branches of science, this simple grease spot would alone have been sufficient to have handed his name down to posterity. Although confronted with innumerable processes, chemical, optical, and photographical, this has calmly held its own; and not all the ingenuity and profound research of modern laboratories has been able to shake it on the throne to which its own simplicity and admirable adaptability to practical photometrical requirements have raised it. Never perhaps in the history of mankind has so humble a thing been so universally honoured. Herr Elster relates the story that a few years ago, when he was showing the late Emperor Frederick of Germany—then Crown Prince—a Photometer, and explaining to him the principle of the Bunsen disc, His Imperial Highness remarked: "For the first time in my life I now know the value of a *spot of grease*." In Bunsen's original Photometer, he enclosed this disc of paper marked with grease in a box in which was burning a small gas-flame. The flame illuminated one side of the disc, the reverse side of which was turned to one of the lights under comparison, and the distance noted. The box was then turned round, so that the disc faced the second light; a second reading was taken, and the distances thus found used for the ordinary calculation. In this form the Bunsen

Photometer did not, however, meet with much favour ; and it was not until Alfred King utilized the idea and constructed the open bar Photometer, using the Bunsen disc simply placed between the two opposing lights, that this system came into general use. The only rival to the grease spot of Bunsen is the star disc devised by Leeson. In the original form, however, it was condemned, in consequence of the misleading results indicated when the three pieces of paper of which it is formed separated from one another, or "cockled" as it is termed. By the method of causing the three pieces to adhere in the form of one, suggested by the Author, this difficulty has been overcome. For comparison of lights of different colour, this disc is admirably adapted, as red and blue coloured lights can be readily compared, which is an impossibility with the Bunsen disc. Those who have to examine arc electric lights will at once understand the advantage of this point. In 1849, Edge fixed the disc at ten inches from the candle—a system which was afterwards adopted by Church and Mann. In 1850, Alexander Wright used stationary lights and a moving disc, after the manner of King. In 1859, Bunsen and Roscoe equalized the illuminating power by varying the angle of incidence of the rays from the stronger light. In 1861, Pouillet used a positive daguerrotype, which was changed in appearance to a negative by an excess of light. Ten years later Wallace used stereoscopic lenses to cause the images of the two sides of the disc to overlap. In 1875, Otto Shuette went back to François' method of 1700 ; but he used thin pieces of paper instead of glass, as the obscuring medium. In 1880 Pickering suggested the contraction of the pupil of a cat's eye as an indication of the power of weak lights.

From time to time various polarizing and spectroscopic methods have been proposed; the latest of these being a rather complicated arrangement of prisms by Grosse, a description of which was read by Dr. H. Kruss, of Hamburg, at the Twenty-eighth Annual Meeting of the German Society of the Gas and Water Profession in 1888. For this polarizing system it is claimed that the length of the Photometer can be altered at will, and that the mixing of the light sources of different colours can be suitably arranged. Various chemical methods have been suggested, notably that by Draper, in 1843, who used as an index the extent to which the gases hydrogen and chlorine were caused to combine by the intensity of the light rays. This system was modified by Bunsen and Roscoe in 1857, who absorbed in water the hydrochloric acid so formed. An electrical method was employed in 1851 by Becquerel, who estimated the intensity and activity of light by means of the electrical current which is caused when two prepared silver plates are placed in water acidulated with sulphuric acid and connected, one of them being exposed to a stronger light than the other. Siemens and Halske proposed to utilize the fact that the electrical resistance of selenium is diminished by the action of light. Various other systems have been devised; but none of them appear to have come into practical use.

Jet Photometers—so called from the indications afforded by the height of a flame or "jet" of gas under the same or varied pressures—were first introduced by Alcock in 1836. In 1849, Fyfe, of Aberdeen, used a similar system, which he called the *durability* test. Lowe, in 1860, proposed his well-known form of Jet Photometer; but the only instrument of the kind now in general use is that known as Kirkham

and Sugg's. In this instrument the height of the jet flame is fixed, and the indications are those afforded by the pressure of the gas required to maintain the flame at the normal height. Strictly speaking, this is not a Photometer, but an indicator—which is correct only in the absence of carbonic acid in the gas. An extension of this method has been worked out by Sugg in the form of the Illuminating Power Meter, which is a handy instrument, and generally very accurate for normal coal gas.; but, correctly speaking, its action as a *Photometer*, like that of the Jet, is only indirect.

So far we have dealt with only that part of the subject which relates to the method of comparing two sources of light. The second branch treats of the standard of light with which the light under examination is to be compared. Although a very great amount of energy has been expended upon this subject, it does not appear that anything like so much attention has been bestowed on it as upon the former branch—probably because the necessity for an accurate standard was not recognized until about thirty years ago, when the rapid growth of the gas companies, and the introduction of a system of legal testing, called for more accurate work. With the introduction of the electric light, and the consequent lowering of the price of gas, a sharper line of demarcation has been introduced between "good" and "bad" gas. Gas authorities have found out that the old slipshod systems of "anything over the standard," which was good enough in days gone by, will no longer answer with keen-questioning directors; and consequently there is more economy now exercised. In this the gas maker is in no way to blame. He undertakes to make and supply a certain article

for a certain price; and he can no more be expected to exceed that bargain than can the family butcher be asked to add an odd ounce or two to every pound of beef that he sells. All that we demand of the butcher is that his pound shall weigh sixteen ounces, and that each ounce shall be correct. In the same way, the gas seller must supply in London at least what is called "sixteen-candle gas"—*i.e.*, gas which, when burnt in a standard burner at the rate of five cubic feet per hour, shall give a light equal to sixteen standard sperm candles. So far all is clear; but as soon as we get to the next step, and ask, "What is a candle?" all is confusion. Thus the necessity for a sharp and definite standard is brought clearly to light, and still more so when it is considered that in London alone the annual value of a "candle" in the illuminating power of "sixteen-candle gas" is, in round numbers, £200,000!

In 1760 we have the first recognition of the necessity for a standard of light, when Bouguer said that the readiest way of recording the intensity of a light was to find out the number of candles required to give the same amount of light. He, however, seemed to think that a candle was a "candle," and nothing more, as he does not give any further particulars. The French standard of light—the Carcel lamp—in which refined colza oil is burnt at the rate of 42 grammes per hour, was introduced in 1800. The value of this standard was found by Sugg, in 1869, to be equal to 9·6 English sperm candles, and by the Author, in 1885, to be 9·4, or a mean of 9·5 candles. The first account we have of the importance of noting the rate of combustion is in 1808, when Murdoch used as a standard tallow candles weighing

six to the pound, and burning at the rate of 175 grains per hour. Some few years later, Lord Stanhope proposed that the wicks of the candles should be waxed before they were coated with tallow; and in 1824, Ritchie used wax candles. Paraffin candles, now in use as the German Standard, were first used by G. Zincken in 1863, when he adopted the standard rate of combustion as 115·2 grains per hour. Stearine candles of six to the pound, and burning at the rate of 169·7 grains (11 grammes) per hour, were used by Vogel. In 1859, Bunsen and Roscoe used a carbonic oxide flame, which burnt 5 cubic centimetres of that gas per second. Fiddes was the originator of the system adopted in the now well-known Methven standard. In 1865, he proposed the use of an Argand flame surrounded by an opaque chimney, having an aperture of a quarter of an inch in diameter at about the middle of the flame. Three years later, Crookes made a most elaborate attempt at a standard. He constructed a lamp fitted with a platinum wick, in which he burnt a mixture of alcohol and benzol. This certainly looks very promising; and it is a matter for regret that it has not been heard of since. In 1867 Bowditch suggested as a standard a hydrogen or carbonic oxide flame rendered luminous by the vapour of pure naphthalene. In 1869, Keates proposed his original pattern of the sperm oil-lamp, which gave a light equal to ten candles. This was subsequently improved by Sugg, in which form the Author found in 1879 that it gave a light equal to sixteen candles, with a consumption of 925 grains of sperm oil per hour. At one time it appeared as if this lamp had a good chance of being adopted as the standard in place of the sperm candles; but very extended experiments have failed to establish its reliability in the hands of different

operators. In 1874, Von Wartha proposed to use a flame obtained by the burning of the vapour of ether; but from his description the quantity of ether required to produce a flame equal to one candle may vary from one ounce to one ounce and a quarter. Probably the variations, however, were due to *the candles!* The now all but generally accepted substitute for candles in this country, known as the pentane air-gas, was introduced by A. G. Vernon Harcourt in 1877. This has been so thoroughly examined and favourably reported upon, that it is to be hoped that the block in the way of its adoption as the legal standard of reference will soon be removed. Whatever the objection may be, it cannot be a rational one on public grounds against the system. The proposal has been recommended by a Committee of the Board of Trade; by the Controlling Authority under the Acts relating to the testing of gas in the Metropolis; and by the Standards of Light Committee of the British Association. There is probably an official hitch which may in some degree be due to the fact that the inventor is one of the Gas Referees. If this be so, it is a matter which may be soon settled, as one of the duties of the Gas Referees is to prescribe from time to time the apparatus to be employed, and the manner in which it is to be used. Finding that the essential part of the apparatus—viz., the standard of light—was inefficient, one of the Gas Referees set to work to improve it. He succeeded; and instead of thankful recognition, his labours have met with obstruction such as to dishearten sensitive men holding official positions from doing more than is sufficient to prevent their work being called into question. In the year 1878, Methven proposed his slotted scheme. In the original

form of the appliance he used plain coal gas; but he afterwards enriched the gas with the vapour of pentane, and reduced the size of the slot through which the light passes to the Photometer disc. In both these forms the proposal has met with much favour. Shortly afterwards Sugg put forward an instrument which had for some time previous been in daily use in his business for testing the illuminating power of burners—viz., the "ten-candle test." In this arrangement the top of a small Argand flame is cut off by a screen; and the light from the bulk of the flame, including the lower or "blue" portion, is used as the standard. The Author afterwards modified this system by causing the burner to consume an air-gas obtained by simply passing air over liquid pentane; the result being a standard independent of coal gas, requiring no measurements for consumption, temperature, or pressure, and admitting a variation of more than an inch and a half in the height of the flame without making any alteration in the volume of light proceeding to the disc. This system is known as the Pentane Argand. In 1884, Herr Von Hefner-Alteneck proposed the amyl-acetate lamp, which has met with such approval in Germany that a large number of operators tentatively use it as a working standard. It is a simple form of spirit lamp, giving a flame 40 millimetres high, caused by the combustion of amylic acetate, better known in commerce under the name of "pear-oil." The illuminating power of the flame is said to be equal to one standard candle; but the Author has found it necessary to raise the height of the flame to 51 millimetres—or two inches—to obtain the light of an average sperm candle. The objection to this standard by the English photometrists is based on the red colour of the

flame, which renders readings of the disc by different operators a matter of uncertainty. When the "Pentane" is better known in Germany, the amyl-acetate lamp will probably have to give way, as, according to Dr. Krüss, the colour of the flame is also objected to there.

In 1843, Draper proposed to use a platinum wire raised to incandescence by a current of electricity; but he did not make any photometric observations, the suggestion being an outcome of work done in another direction. Zollner and Schwendler made similar proposals; and in 1880 Violle employed the light emitted from a cubic centimetre of platinum at the moment of its greatest brilliancy—when just beginning to solidify after being in a molten state. This system so impressed the members of a Congress of Electricians which sat in Paris that they recommended it as a standard. In 1881, however, another Congress rejected it, and recommended the Carcel lamp.

Having thus glanced at the gradual development of the two essential features of a "Photometer," it only remains to consider the introduction and improvement of its surroundings—such as the outer casing, &c.

King applied the disc system of Bunsen, and used a simple graduated bar, at one end of which was placed the light to be tested, while at the other was the standard with which it was to be compared. In the middle of the bar, the Bunsen disc was conveniently mounted for the purpose of adjustment at the right distance between the two lights. The instrument was used in a dark room. At one time the bar was 100 inches long, and only one candle was used. Church and Mann fixed the candle to the carriage which supports the disc at a

distance of ten inches from the latter. Elster, in 1860 used the same arrangement, but employed a small gas-jet in place of the candle. The 100-inch bar used by King was afterwards shortened to 60 inches by Letheby; and the disc was enclosed in a sighting-box which travelled on wheels along the bar. When fitted in a small portable room, this instrument is known as the "Canadian." In 1858, in consequence of a dispute with the St. James's Vestry as to the illuminating power of the street lamps, it was decided to test the burners *in situ*, as the authorities would not consent to their removal to a proper testing-room. Accordingly a closed Photometer was constructed under the direction of the late Mr. F. J. Evans, then Engineer of The Gas-Light and Coke Company. The end of this Photometer could be placed bodily over the street lamp. The disc was fixed at a point 50 inches from the flame; and the candles mounted on a travelling holder on the reverse side of the disc. This questionable arrangement, involving several most objectionable principles, found such favour with the inventor, that when he afterwards became one of the Gas Referees, he obtained its adoption at the London gas-testing stations. In the history of Photometry this forms an interesting lesson. Had the local authorities been content to have had the gas conducted from the lamp-post to a proper testing-room in the near neighbourhood, and the burners taken there for examination, the arrangement of putting up a Photometer in the street would never have been brought about; the Evans Photometer in all probability would never have been invented; and a long backward stride in the art of Photometry never have been taken. By their objection to the removal of the burners, the authorities

simply made a lash for their own backs, as they were outwitted by the necessary introduction of a system of testing disadvantageous to themselves.

The moving of the candles in the Evans Photometer having long been admitted as a serious error, Keates suggested, in 1880, a modified form, in which the candles should be fixed and the screen made movable, as in the Letheby open bar. Sugg afterwards improved upon Keates's suggestion by putting the lights in towers, freely ventilated at each end of the enclosed bar. In this form the instrument is known as the "Tower" or "Imperial" Photometer. This principle of burning both the gas and candles in a large volume of air moving at a slow speed, laid down by the Author some years ago, has given admirable results, and has been employed in the latest form of open-bar Photometers adopted by the Gas Referees.

In 1882, Hartley brought out his "Universal" Photometer, which was designed to facilitate the testing of burners of different powers, and for testing the quantity of light received upon a *vertical* surface from burners at various heights. At the Author's suggestion, the disc was arranged so that it could be adjusted at any required angle, in order that the rays from the standard and from the burner under examination, whatever its position, might impinge upon the screen at equal angles. For the purpose of facilitating the testing of the rays of light emitted from gas-burners and other sources of illumination, the Author devised the "Radial" Photometer, which he described before the Society of Chemical Industry in May, 1884. At the same time a portable Photometer was shown, which is, for all purposes of horizontal testing, as correct as the most elaborately finished

example of the Photometer maker's skill. A new form of reflecting Photometer has recently been devised by Harcourt, which he has called the "Holophotometer." It is designed, like the "Radial," to estimate the intensity of the rays of light emitted in all directions. The Table Photometer of the same gentleman is a modification of Foucault's, which is much used in France.

In addition to the foregoing, various contrivances have from time to time been proposed, of which space does not permit a description in these pages—which, being devoted to practical Photometry, will be fully taken up with matters of detail relating to actual working methods. Should the reader desire to follow out more closely the historical portion of the subject, he cannot do better than consult an admirable work on "Photometry and Gas Analysis" by J. T. Brown, F.C.S., who has carefully compiled an excellent digest of all that has been done up to a comparatively recent period in the various branches of those interesting departments of science.

## CHAPTER II.

## PRINCIPLES OF PHOTOMETRY.

THE first law of Photometry is that relating to inverse squares. Light proceeds from a given radiant in all directions in straight lines. Consequently, it follows that, as these lines recede farther from the starting point, they separate more and more; and thus a less volume of light impinges upon a given object the more remote its distance may be, and this reduction is in inverse ratio to the square of the distance. The following diagram will help the student to comprehend this fundamental law.

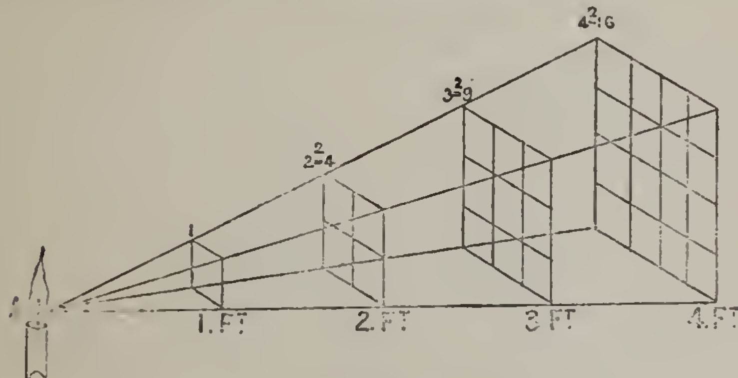


Fig. 1.

Let it be assumed that the four diverging lines enclose a number of rays of light proceeding from the radiant A. At a distance of one foot, the whole of these rays would fall

upon a screen of small dimensions. At twice that distance they would illuminate a surface four times the size of the first screen; and, consequently, the volume of light impinging upon a screen the same size as that at one foot distance would be only *one-fourth*.

At three feet distance, the whole of the rays would have spread, so that a screen nine times the size of the first would be required to arrest them all, and, therefore, our small screen, if removed to that position, would receive only *one-ninth* of its primary illumination. In like manner, at four feet distance, a screen sixteen times the size of the first would be necessary; so that our unit screen at that distance would receive only one-sixteenth of the light it would at one foot. This is a simple point, but in experimental work away from the regulation instruments, it is absolutely necessary to clearly comprehend it.

To compare one light with another of similar colour, we interpose between them either a Bunsen disc, (which is a piece of paper having either a grease spot in the centre, or a greased circumference leaving the middle untouched), or, for lights of different colour, the Author's improved Leeson disc (which is made of three pieces of paper, the two outer ones of thin paper, and the centre one thick, with a star-shaped piece removed from the middle), and notice the character of the illumination on either side. If one side is brighter than the other, the disc is moved until the illumination on either side is equal. To calculate the value of one light in terms of the second, we must first measure the distance of each from the disc, and then divide the square of the distance of the greater by the square of the distance of the lesser.

Thus, suppose the distance of the disc is 12 inches from the standard light, and 48 inches from the light whose intensity it is desired to ascertain, then—

$$12^2 = 144, \text{ and } 48^2 = 2304.$$

| | |
|---|---|
| 144)2304(16 | = the intensity of the light |
| 144 | under test, in terms of the |
| 864 | value of the standard |
| 864 | employed. |

If the standard of comparison is more than one candle in value, the result so found must be multiplied by the value of the standard, when the illuminating power of the opposed light will be obtained in terms of standard candles—that is, when the light opposed to the standard is in excess. If the opposed light is less than the standard, the calculation must be reversed.

Thus, let it be assumed that the intensity of the standard is 16 candles, and the light whose value is required unknown, while the position of the disc from the two lights is as above, then—

$$12^2 = 144, \text{ and } 48^2 = 2304.$$

| | |
|---|---|
| 2304)144·00(·0625 | = the intensity of |
| 138·24 | the light under |
| 5760 | test, in terms |
| 4608 | of the value |
| 11520 | of the standard |
| 11520 | employed. |

As the value of the standard was known to be 16 candles, we have $\cdot 0625 \times 16 = 1$ candle = the value required.

In order that the indications of the disc may be reliable, it is necessary to take several precautions. First, the comparison must not take place in daylight, or in the presence of any other lights which might, by shining upon the disc,

vitiate the result. Secondly, it is necessary to avoid reflection from surrounding objects. And, thirdly, the disc must be turned alternately with one side first to one burner and then to the other, as occasionally it happens that a disc will give erroneous results when not properly prepared.

From the foregoing, it would appear that the operations are very simple ; and, so far, they are. The chief difficulty, however, lies in the uncertainty of our standard of comparison. If this were definite and easily obtained, little more would have to be done ; but at present the standard candle is not by any means definite, and we have accordingly to make the best correction we can for its variations. This is done by weighing the sperm consumed in a given time ; and, assuming that the variation in intensity will be proportional to the consumption, calculate the intensity of light on the assumption that unit sperm gives unit light. The beginner will soon find that this is an "assumption" only. Fortunately, when not tied down by official routine, there is no difficulty in overcoming the trouble, by adopting one of several substitutes for candles, and thus ensuring the accuracy of the observations.

In ordinary gas testing, in which work the major portion of most photometrists' time is employed, it is necessary to apply further corrections, and to make certain observations to ensure a normal rate of consumption of the gas in the standard burner. For this purpose the gas is controlled by a "governor" to ensure its steady flow to the burner, and measured by a "meter" of delicate construction, so as to indicate, by observations of one minute, the rate at which the gas is being burnt. The quantity consumed is usually 5 cubic feet per hour ; and this should give 14, 16, or

20 " candles " of light according to its quality. Here, again, care must be taken to ensure the gas being burnt in a burner suitable to its intensity, as it would be impossible to consume 5 cubic feet of 20-candle gas in an Argand burner constructed to burn only 14 or 16 candle, or " common " gas, as it is often called. Rich gases of 20 candles and over are therefore burnt in flat-flame burners, while " common " gases are burnt in Argand burners. In the latter case, different sized burners are in use, and even different sized glass chimneys with the same burner for different gases. So that before a photometrist commences to test, he first inquires as to the " quality " of the gas, and then chooses the burner prescribed for that particular gas. This doubtless appears to be very confusing, and unquestionably it is so. There is no reason beyond the " Act of Parliament " why one standard Argand burner should not be adopted for all gases; and that sufficient gas should be consumed to produce a given height of flame, which, having been tested as to its illuminating power, should form a basis of calculation as to the quality of the gas. This system in a slightly altered form has been in use in France for a long time past, the difference consisting in the fact that they turn on the gas until a given illumination is obtained, and then state the results in percentages of the quantity of gas required to produce a given light. Mr. A. G. Vernon Harcourt has suggested such a method as being suitable for adoption in this country. Some eighteen years ago Dr. Pole, one of the Metropolitan Gas Referees, published an article in the *Journal of Gas Lighting* on the influence of gas-burners. Dr. Pole had analyzed a number of

* See Vol. XIX., pp. 7788, 13.

published results of tests of gas-burners; and he deduced from them the law that the light yielded by any gas from any burner varied in the ratio of the quantity of gas burnt, *minus* a constant or subtractive quantity. Or, in other words, a point (in quantity) arrives where a normal and proper condition (of combustion) is reached; and *beyond that point every increment of gas gives a corresponding and uniform increment of light.* The "normal and proper condition" relates to *quantity of gas;* and this quantity Dr. Pole calls the "developant" of the burner for the quality of the gas burnt. Further on he says: "The law is that, in a given burner, taken through its normal range, the light given varies as the quantity of gas consumed, *minus a constant quantity.* That is, if L represents the photometric amount of light produced by the consumption of $q$ cubic feet of gas per hour, then—

$$L = A(q - c)$$

where A and $c$ are constants for the same gas and the same burner." Messrs. Heisch and Hartley referred to the above quotation in a paper read by them before The Gas Institute in 1884, in which they gave the results of a number of experiments upon this point; and also the following:—

*Rules for the use of the factors "A" and "c" when it is desired to express the power of any gas at 5 cubic feet rate per hour:—*

1. Correct the actual rate of consumption for barometric pressure, and for temperature of the gas, by the aid of factors in the published tables.
2. Multiply the difference between the actual rate of consumption (corrected) and 5 cubic feet by the

factor "A" due to the quality of the gas. (a) If the rate of gas be *below* 5 cubic feet, *add* the product to the observed amount of light. (b) If the rate be *above* 5 cubic feet, *subtract* the product from the observed amount of light.

The following abstract is taken from Messrs. Heisch and Hartley's valuable paper :—

"The following table of actual tests with gas of very nearly 15-candle power exemplifies our method; while the last column shows the grave errors which result from the present system of correcting illuminating power to the standard rate. Only ordinary care was taken in making the tests, as may be judged when the fact is stated that the whole series of observations were completed in half an hour.

TABLE *showing the New Method of Correcting for Rate.*

Nearly 15-candle Gas; Multiplier, 6·3.

| Rate of Gas by Meter. | Tabular No. | Corrected Rate for Gas. | Excess or Deficit in Rate. | Product of Excess or Deficit and Multiplier. | Observed Illum. Power. | Illum. Power. Corrected to 5 feet rate. | Calculated to 5 Cubic Feet Rate by Old Rule. |
|---|---|---|---|---|---|---|---|
| 4·250 | 994 | 4·225 | ·775 | 4·890 | 9·80 | 14·690 | 11·600 |
| 4·400 | 994 | 4·374 | ·626 | 3·946 | 10·90 | 14·846 | 12·460 |
| 4·500 | 994 | 4·473 | ·527 | 3·235 | 11·50 | 14·735 | 12·850 |
| 4·600 | 994 | 4·572 | ·428 | 2·696 | 12·10 | 14·796 | 13·232 |
| 4·700 | 994 | 4·672 | ·328 | 2·066 | 12·82 | 14·886 (?) | 13·720 |
| 4·800 | 994 | 4·772 | ·228 | 1·376 | 13·40 | 14·776 | 14·040 |
| 4·850 | 994 | 4·821 | ·179 | 1·128 | 13·80 | 14·928 | 14·313 |
| 5·000 | 994 | 4·970 | ·030 | 0·189 | 14·72 | 14·909 | 14·808 |
| 5·072 | 994 | 5·038 | ·038 | 0·239 | 15·00 | 14·761 | 14·876 |
| 5·370 | 994 | 5·338 | ·338 | 2·139 | 16·70 | 14·561 | 15·642 |
| Per cent. extreme differences . . . | | | | | | 2·500 | 34·800 |

"The method of Dr. Pole is illustrated in the diagram, the ordinates in which express the illuminating power, and the abscissæ the rates of gas consumption per hour. The dots enclosed in circles coincide in their positions with observed illuminating powers and with rates of gas consumption. The slant line cuts the mean line of the dots, which represent results that are nearest in agreement, and the line extended or produced also cuts the first ordinate at a point above its origin. The number of abscissæ included between the zero and the cutting-point of the slant line gives the value in cubic feet (or parts) of the "developant" *c* for the burner with the quality of the gas used. The multiplication of this by the number of accepted experiments, and its division upon the sum of the accepted illuminating powers for various rates of consumption, should give the number or multiplier A; but as, even in what appear concordant experiments, discrepancies exist, the exact value of A can only be ascertained by calculations throughout the whole series of correct results.

"The values of *c* and A can also be found arithmetically, but by this plan we lose the advantage which belongs to the graphic method; the latter indicating discrepancies which are not very evident in a mere sheet of tabulated results.

"The best arithmetical method is as follows:—Divide *seriatim* the difference between each consecutive pair of results by the differences between their gas consumptions; the quotients should all be nearly equal. Then the average of the whole will be the value of the multiplier A. To find the value of *c*, divide the respective observed illuminating powers by the number A above found; the average of the

Dr. Pole's Law.—15-Candle Gas.

$c = 2{\cdot}63. \qquad A = 6{\cdot}3.$


PLATE No. 1.

whole deducted from the average of the consumption rates should leave a remainder equal to the value of the "developant" $c$. Here, again, precise judgment must be exercised. The experiments should not be less than eight or ten in number at different rates of consumption; and if the factors $c$ and A thus obtained give for any experiment a result very discordant with the rest, such experiment must be rejected, and new values found from the rest for $c$ and A. There is really no great difficulty in ascertaining these values; patience and judgment only being necessary. But patience will be severely taxed unless the photometric tests have been made with the greatest possible care.

"One important fact we must here express. It is that, even as you cannot get effective work from a steam or gas engine by merely burning sufficient fuel to generate force enough to overcome the resistance or friction of the engine, so it is with a gas-burner; you cannot get it to perform its effective duty when burning only the bare quantity of gas requisite for its "developant." More, and much more, must sometimes be burnt before the effect of the "developant" quantity is really felt. Thus, in the tests which we made with a Sugg "K" Argand burner, having a 2-inch by 9-inch chimney, and with gas which we estimated, when using a standard "London" Argand, to be of nearly 45-candle power, we were obliged to double the "developant" quantity of gas before consistent and regular results were obtained. This fact in no degree lessens the value of Dr. Pole's law and of our rules.

*Sugg "K" Argand.—Very Rich Gas.*
"Developant" $c =$ 1·55 cubic feet.
Multiplier A = 11·50 ,,

| — | Corrected Rate of Gas. | Observed Illum. Power. | Illum. Power, Pole's Law. | Illum. Power for 5 Cubic Feet, Our Rule. | Illum. Power for 5 Cubic Feet, Old Rule. |
|---|---|---|---|---|---|
| | Cubic Feet. | Candles. | Candles. | Candles. | Candles. |
| No. 1 .. .. | 3·276 | 19·60 | 19·85 | 38·82 | 29·92 |
| ,, 2 .. .. | 3·473 | 20·26 | 21·11 | 38·16 | 29·16 |
| ,, 3 .. .. | 3·768 | 26·00 | 25·61 | 39·17 | 34·58 |
| ,, 4 .. .. | 4·100 | 29·63 | 30·48 | 39·99 | 36·13 |
| ,, 5 .. .. | 4·254 | 31·80 (?) | 30·10 | 40·38 (?) | 37·37 (?) |
| ,, 6 .. .. | 4·854 | 37·73 | 38·00 | 39·40 | 38·87 |
| ,, 7 .. .. | 4·935 | 39·05 | 38·93 | 39·80 | 39·56 |
| ,, 8 .. .. | 5·220 | 41·91 | 42·20 | 39·38 | 40·14 |
| Extreme differences per cent. . . . . | | | | 4·80 | 34·20 |

*Note.*—The experiment No. 5 is discordant, and has been omitted in calculating the percentage differences.

"The next table shows the results obtained with the same sample of gas burnt from the "London" Argand; and calculated to 5 cubic feet, indicates the real relative value of the gas.

*Standard "London" Argand.—Very Rich Gas.*
"Developant" $c =$ 0·71 cubic feet.
Multiplier A = 10·40 ,,

| — | Corrected Rate of Gas. | Observed Illum. Power. | Illum. Power, Pole's Law. | Illum. Power for 5 Cubic Feet, Our Rule. | Illum. Power for 5 Cubic Feet, Old Rule. |
|---|---|---|---|---|---|
| | Cubic Feet. | Candles. | Candles. | Candles. | Candles. |
| No. 1 .. .. | 2·2959 | 16·52 | 16·49 | 44·64 | 35·98 |
| ,, 2 .. .. | 2·2613 | 16·00 | 16·13 | 44·48 | 35 34 |
| ,, 3 .. .. | 2·1397 | 14·87 | 14·87 | 44·62 | 34·75 |
| ,, 4 .. .. | 1·8566 | 12·19 | 11·92 | 43·88 (?) | 32·83 |
| ,, 5 .. .. | 1·7875 | 11·54 | 11·42 | 44·95 | 32·28 |
| ,, 6 .. .. | 1·7450 | 10·76 | 10·97 | 44·61 | 30·74 |
| Extreme differences per cent. . . . . . | | | | 0·70 | 17·00 |

"It will be observed that the values of both constants are lower than with the "K" burner. The "developant" is less than half that of "K," while A is less only by about 10 per cent. Owing to the large reduction in *c* and the small reduction in A, this burner does better for the gas than the larger burner in respect of indicated illuminating power.

"In view of the concord which exists between our deductions and those of Dr. Pole, and also in view of the close approximation to equality in the results of calculations to the 5 cubic feet rate by our rules, we venture to ask: Why should not the present erroneous practice be discarded and abolished, and why should not the standard "London" Argand burner be universally adopted as the testing burner for all qualities of gas throughout the United Kingdom? In order to help in bringing about so desirable a consummation, we have formulated a few tables, by the aid of which the probable value for 5 cubic feet of certain gases burnt, at the Photometer, from the "London" Argand, may be inferred from the results of observations at other rates of consumption. These tables are, for the most part, based on a theoretical or speculative application of Dr. Pole's law; and they need to be confirmed or otherwise by the operations of other experts in Photometry. We do not think, however, that the figures of the tables will be found very far removed from the truth. If experts generally will address themselves to this matter, there can be no doubt that a better understanding of the relation of the carbon density of the illuminants of coal gas to the actual illuminating power will be obtained; and both scientific and practical men will be benefited thereby.

"Cannel gas is used to enrich ordinary gas, which has, when tested, to be burnt from the Argand; yet, strangely (and certainly illogically), the value of the cannel gas made to be so admixed is generally estimated by its lighting power when burnt in a flat flame. Truly, gas makers know the significance of such tests; but we trust they will be disposed to adopt the more consistent and rational method we advocate."

TABLE I.

| | *Candles.* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| About | 10·0 | 11·0 | 12·6 | 13·0 | 13·5 | 14·0 | 14·5 | 15·0 | 16·0 |
| Rate of Gas per Hour. | *c* 3·06 | *c* 2·99 | *c* 2·9 | *c* 2·89 | *c* 2·85 | *c* 2·78 | *c* 2·7 | *c* 2·63 | *c* 2·54 |
| | A 5·14 | A 5·5 | A 5·04 | A 6·12 | A 6·2 | A 6·25 | A 6·3 | A 6·3 | A 6·5 |
| 4·0 .. .. .. .. | — | — | — | 6·79 | 7·13 | 7·63 | 8·19 | 8·63 | 9·49 |
| 4·1 .. .. .. .. | — | — | 7·25 | 7·41 | 7·75 | 8·25 | 8·82 | 9·26 | 10·14 |
| 4·2 .. .. .. .. | — | 6·66 | 7·85 | 8·02 | 8·37 | 8·88 | 9·45 | 9·89 | 10·79 |
| 4·3 .. .. .. .. | 6·37 | 7·21 | 8·46 | 8·63 | 8·99 | 9·50 | 10·08 | 10·52 | 11·44 |
| 4·4 .. .. .. .. | 6·89 | 7·71 | 9·06 | 9·24 | 9·61 | 10·13 | 10·71 | 11·15 | 12·09 |
| 4·5 .. .. .. .. | 7·40 | 8·31 | 9·67 | 9·85 | 10·23 | 10·75 | 11·34 | 11·78 | 12·74 |
| 4·6 .. .. .. .. | 7·92 | 8·56 | 10·27 | 10·47 | 10·85 | 11·38 | 11·97 | 12·41 | 13·39 |
| 4·7 .. .. .. .. | 8·43 | 9·41 | 10·87 | 11·08 | 11·47 | 12·00 | 12·60 | 13·04 | 14·04 |
| 4·8 .. .. .. .. | 8·94 | 9·96 | 11·48 | 11·69 | 12·09 | 12·63 | 13·32 | 13·67 | 14·69 |
| 4·9 .. .. .. .. | 9·46 | 10·51 | 12·08 | 12·30 | 12·71 | 13·25 | 13·86 | 14·30 | 15·34 |
| 5·0 .. .. .. .. | 9·97 | 11·06 | 12·68 | 12·91 | 13·33 | 13·88 | 14·69 | 14·93 | 15·99 |
| 5·1 .. .. .. .. | 10·49 | 11·61 | 13·29 | 13·53 | 13·95 | 14·50 | 15·12 | 15·56 | 16·64 |
| 5·2 .. .. .. .. | 11·00 | 12·16 | 13·89 | 14·14 | 14·57 | 15·13 | 15·75 | 16·19 | 17·29 |
| 5·3 .. .. .. .. | 11·51 | 12·71 | 14·47 | 14·78 | 15·19 | 15·75 | 16·38 | 16·82 | E |
| 5·4 .. .. .. .. | 12·03 | 13·26 | 15·10 | 15·36 | 15·81 | 16·38 | 17·01 | 17·45 | |
| 5·5 .. .. .. .. | 12·54 | 13·81 | 15·60 | 15·97 | 16·43 | 17·00 | 17·64 | E | |
| 5·6 .. .. .. .. | 13·06 | 14·36 | 16·10 | 16·58 | 17·05 | | E | | |
| 5·7 .. .. .. .. | 13·57 | 14·91 | 16·60 | 17·19 | E | | | | |
| 5·8 .. .. .. .. | 14·18 | 15·46 | 17·10 | E | | | | | |
| 5·9 .. .. .. .. | 14·69 | 16·01 | E | | | | | | |
| | E | | | | | | | | |

*Example* :—Observed light for 4·8 ft. = 14·5 c.
A for 16 c. gas is nearest
and 0·2 × 6·5 = 1·3

Illum. power of gas = 15·8 c.

The figures in the columns marked E are deduced from experiments; the remainder are theoretical.

## TABLE II.

*Candles.*

| About | 17·0 | 18·0 | 19·0 | 20·0 | 21·0 | 22·0 | 23·0 | 24·0 | 25·0 | 26·0 | 27·0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rate of Gas per Hour. | c 2·5 | c 2·4 | c 2·3 | c 2·25 | c 2·2 | c 2·15 | c 2·09 | c 2·04 | c 2·0 | c 1·94 | c 1·9 |
| | A 6·8 | A 6·9 | A 7·1 | A 7·3 | A 7·5 | A 7·7 | A 7·9 | A 8·1 | A 8·3 | A 8·5 | A 8·7 |
| 4·9 .. | 16·32 | 17·31 | | | | | | | | | |
| 4·8 .. | 15·64 | 16·62 | | | | | | | | | |
| 4·7 .. | 14·96 | 15·93 | 17·04 | | | | | | | | |
| 4·6 .. | 14·28 | 15·24 | 16·73 | 17·16 | | | | | | | |
| 4·5 .. | 13·60 | 14·55 | 16·02 | 16·44 | 17·25 | | | | | | |
| 4·4 .. | 12·92 | 13·86 | 15·31 | 15·73 | 16·50 | 17·33 | | | | | |
| 4·3 .. | 12·24 | 13·17 | 14·60 | 15·01 | 15·75 | 16·56 | 17·46 | | | | |
| 4·2 .. | | 12·48 | 13·89 | 14·30 | 15·00 | 15·79 | 16·67 | 17·50 | | | |
| 4·1 .. | | | 13·18 | 13·59 | 14·25 | 15·02 | 15·88 | 16·69 | 17·43 | | |
| 4·0 .. | | | 12·47 | 12·88 | 13·50 | 14·25 | 15·09 | 15·88 | 16·60 | 17·19 | |
| 3·9 .. | | | | 12·17 | 12·75 | 13·48 | 14·30 | 15·07 | 15·77 | 16·34 | 17·40 |
| 3·8 .. | | | | | 12·00 | 12·71 | 13·51 | 14·26 | 14·94 | 15·49 | 16·53 |
| 3·7 .. | | | | | | | 12·72 | 13·45 | 14·11 | 14·64 | 15·66 |
| 3·6 .. | | | | | | | | 12·64 | 13·28 | 13·79 | 14·79 |
| 3·5 .. | | | | | | | | | 12·35 | 12·94 | 13·92 |
| 3·4 .. | | | | | | | | | | 12·09 | 13·05 |
| 3·3 .. | | | | | | | | | | | 12·18 |

## TABLE III.

*Candles.*

| About | 28·0 | 29·0 | 30·0 | 31·0 | 32·0 | 34·0 | 37·0 | 39·0 | 41·0 | 43·0 |
|---|---|---|---|---|---|---|---|---|---|---|
| Rate of Gas per Hour. | c 1·86 | c 1·82 | c 1·77 | c 1·73 | c 1·67 | c 1·57 | c 1·3 | c 1·12 | c 1·0 | c 0·8 |
| | A 8·9 | A 9·1 | A 9·2 | A 9·5 | A 9·6 | A 9·9 | A 10·05 | A 10·1 | A 10·2 | A 10·3 |
| 3·8 .. .. | 17·27 | | | | | | | | | |
| 3·7 .. .. | 16·38 | 17·11 | | | | | | | | |
| 3·6 .. .. | 15·49 | 16·20 | 16·84 | | | | | | | |
| 3·5 .. .. | 14·60 | 15·29 | 15·92 | 16·82 | | | | | | |
| 3·4 .. .. | 13·71 | 14·38 | 15·00 | 15·87 | 16·51 | | | | | |
| 3·3 .. .. | 12·82 | 13·47 | 14·08 | 14·92 | 15·55 | | | | | |
| 3·2 .. .. | | 12·56 | 13·16 | 13·97 | 15·59 | 16·14 | | | | |
| 3·1 .. .. | | | 12·24 | 13·02 | 13·63 | 15·15 | | | | |
| 3·0 .. .. | | | | 12·07 | 12·67 | 14·16 | | | | |
| 2·9 .. .. | | | | | | 13·17 | 16·09 | | | |
| 2·8 .. .. | | | | | | 12·18 | 15·08 | | | |
| 2·7 .. .. | | | | | | | 14·08 | 15·97 | | |
| 2·6 .. .. | | | | | | | 13·07 | 14·96 | 16·32 | |
| 2·5 .. .. | | | | | | | 12·07 | 13·95 | 15·30 | |
| 2·4 .. .. | | | | | | | | 12·94 | 14·28 | 16·48 |
| 2·3 .. .. | | | | | | | | | 13·26 | 15·45 |
| 2·2 .. .. | | | | | | | | | 12·24 | 14·42 |
| 2·1 .. .. | | | | | | | | | | 13·39 |
| 2·0 .. .. | | | | | | | | | | 12·36 |

The following figures are deduced by the authors from the foregoing tables :—

| 35 C. | 45 C. |
|---|---|
| $c$, 1·5 ; A, 10·0. | $c$, 0·71 ; A, 10·4. |
| Feet. Cand. | Feet. Cand. |
| 2·7 = 12·0 | 1·9 = 12·38 |
| 2·8 = 13·0 | 2·0 = 13·46 |
| 2·9 = 14·0 | 2·1 = 14·50 |
| 3·0 = 15·0 | 2·2 = 15·54 |
| 3·1 = 16·0 | 2·3 = 16·58 |
| 3·2 = 17·0 | |

The authors advocated a change of system, because in ordinary practice the value of rich gases was under-estimated ; and in testings made with all sorts and varieties of burners, there was no such consistency as would render chemical analyses of such value as they might possess. The method, said Mr. Hartley, now propounded, was an exceedingly simple one to practise, and gave results which appeared to be concordant and reliable for all qualities of gas from 10 up to 45 candle power.

## CHAPTER III.

## HORIZONTAL PHOTOMETERS.

THE instrument now generally known as a Photometer is so varied in its construction that it is only by keeping in mind the principle of the law of inverse squares, and the action of the disc, that it is possible for the student to recognize the instruments in daily use. The traditional way to make a "new" Photometer is to alter the wooden casing as much as possible; and then to call this outcome of the cabinet maker's art a new Photometer. Thus we have as developments of the open bar of King (in which he employed the principle of the Bunsen disc, which, after all, is the only portion of the instrument that is strictly a Photometer, or light measurer), the "Evans," the "Letheby," the "Keates," the "Canadian," the "Improved Letheby," the open "Evans," the "Tower" or "Imperial," the "Universal," and, when used for horizontal rays, the "Radial;" but as this last-named instrument is specially adapted for testing the rays of light emitted in all directions, it cannot be said to be a copy of the open bar.

*King's Photometer.*—This instrument consisted of an open bar 100 inches long, with the Bunsen disc mounted in a holder riding on the bar. It was used in a dark room, and was as free from accessory apparatus as possible.

*Letheby* improved this form by shortening the bar to 60

inches and using two candles instead of one—two undoubted advantages. He also placed the disc in a "sighting" box, and fitted two small mirrors at the back of the disc carrier

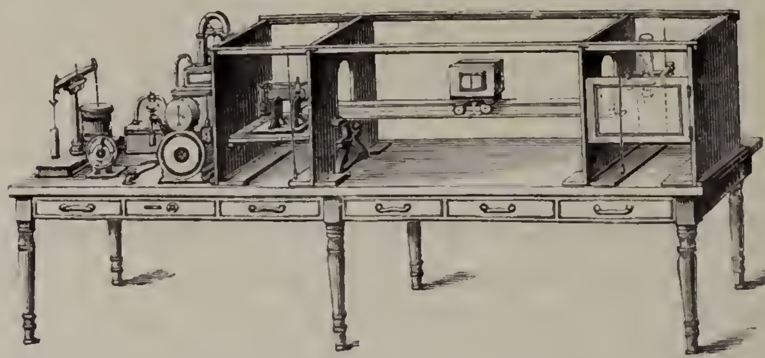

FIG. 2.—LETHEBY PHOTOMETER.

at such an angle that the reflections of the two sides of the disc are viewed simultaneously by the operator standing in front. Screens are also provided for cutting off the direct rays of the two lights from the eyes of the observer. The gas-burner and candles were surrounded with large boxes open at the top and partially so at one side. The disc was indifferently either Bunsen's or Leeson's. The instrument was used in a darkened room.

*The Canadian.*—For the purpose of avoiding the necessity of a darkened room, and to comply with the requirements of the Standards Department of the Board of Trade when certifying this instrument for the Canadian Government, the whole of the subsidiary apparatus, as well as the bar was enclosed in a small wooden room, shut in with heavy curtains; and in this form the Letheby Photometer is known as the "Canadian."

*Keates* used a similar arrangement to Letheby; but preferred the bar to be 75 inches long, and fitted the sighting

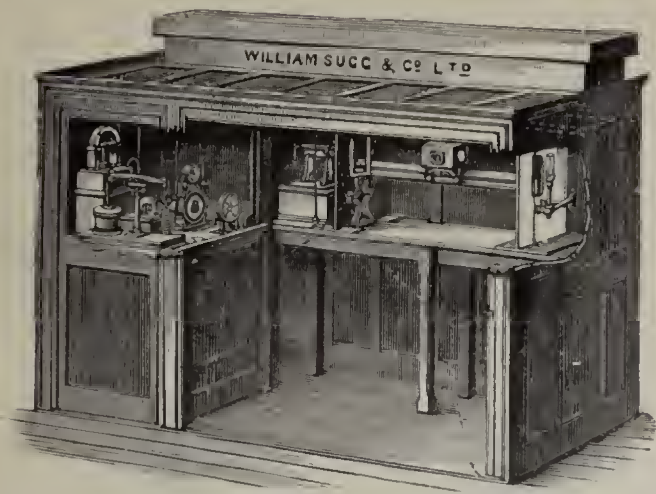


Fig. 3.—The "Canadian Government" Photometer.

box with a metallic screen for the better protection of the observer's eyes. The most important improvement effected by him, however, was the addition of the balance known by his name, which is now supplied to all Photometers fitted for candles. As the movement of these very variable standards should be as small as possible, so that their flames may be in a horizontal line with the disc, Keates constructed a balance on the steel-yard principle—the candles being on the short, and the counter-weights on the longer arm.

A questionable improvement was made on the simple Keates balance by Goodwin, who placed on the longer arm a rod carrying a sliding weight, in order to obviate the necessity for making up for the loss of weight caused by the combustion of the candles, by the addition of shot to the pan under the candles. As this sliding weight occasionally slipped from its position, and thus vitiated the test, the Author suggested the cutting of a screw thread, by which means the uncertain action of the slide was obviated. From a very considerable experience of these balances, however,

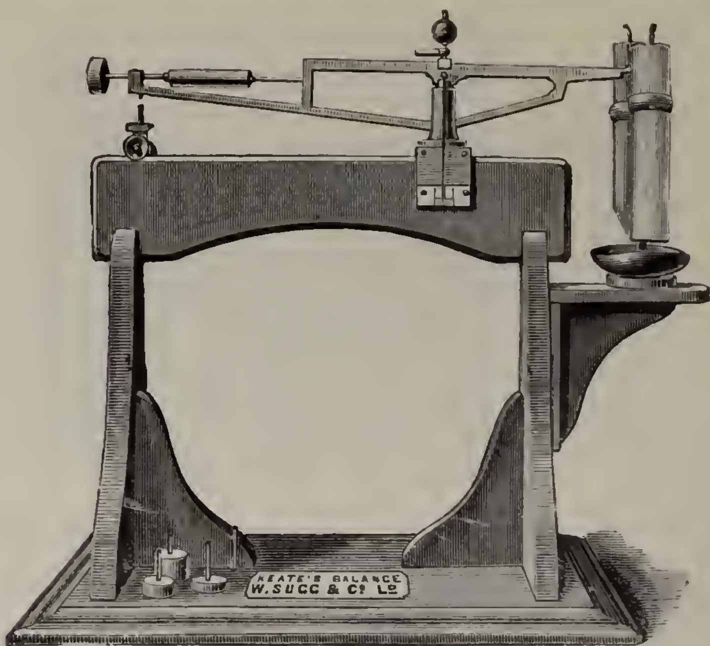


Fig. 4.—Keates's Improved Candle Balance.

the Author does not consider them superior to the original simple pattern of Keates. The use of shot is not obviated, as they afford the most delicate adjustment of the counterpoise when arranging the balance for a test; and, moreover, the indications of the balance are not the same when a heavy weight is being carried as when the candles are lighter. The variations in the indications from the beginning to the end of a single test are certainly not great; but balances of this type are not unknown which, while working well with one weight, do not turn at all so freely, in consequence of the alteration of the centre of gravity, when that weight is replaced with a heavier or lighter one.

*The Improved Letheby* is a recent production, and embodies several points of advantage. In the course of a series of experiments on the standards of light, the Author found that the Pentane flame of Mr. Harcourt did not burn satisfactorily

in the ordinary Letheby Photometer, as the draughts were too variable. If a room perfectly free from draught can be secured, doubtless the open bar of King would answer all that is required; but as the Pentane flame is very sluggish, it is necessary to take precautions. It is also a matter of common observation that in the older forms of Photometers the gas-flame in the Standard Argand burner is never still, but always leaping up and down in a most restless manner. It was therefore found to be of considerable advantage to cover the top of the large chamber, leaving a 6-inch circular opening for the exit of the vitiated air; and to close the part left open *over* the glazed front. The effect was to immediately steady the flames in a most satisfactory manner; and far more concordant results were indicated in consequence. The steadiness of the flames was also found to conduce to much greater facility in the readings. The principle adopted consisted in securing a considerable volume of air moving at a slow speed, free from side or top draughts. This Photometer is also fitted with the Author's reversible disc-holder, which greatly facilitates the operation of reversing the disc and mirrors—a process hitherto more honoured in the breach than in the observance, as the difficulty of effecting the change in the older patterns was but a premium to the neglect of so obvious a precaution. The new mounting of the sighting-box devised by Mr. Sugg is also a great improvement. Instead of a mirror or prism being fitted to the box, and reflecting a constant light upon the scale, a mirror is fixed upon a support standing upon the table, and a beam of light reflected from the gas end of the Photometer directly on the scale. This beam, however, is obstructed by a falling velvet curtain, which is lifted when

a reading is taken. The scale is consequently in shadow during the reading of the disc—a precaution against bias that even the most conscientious observers will appreciate. The candle balance is so mounted that the candle flames can be accurately centred to the plumb lines indicating the end of the bar by means of a screw movement—a refinement due to Mr. Harcourt. This pattern of Photometer is the latest one approved by the Gas Referees; and in practice it is the most convenient of all.

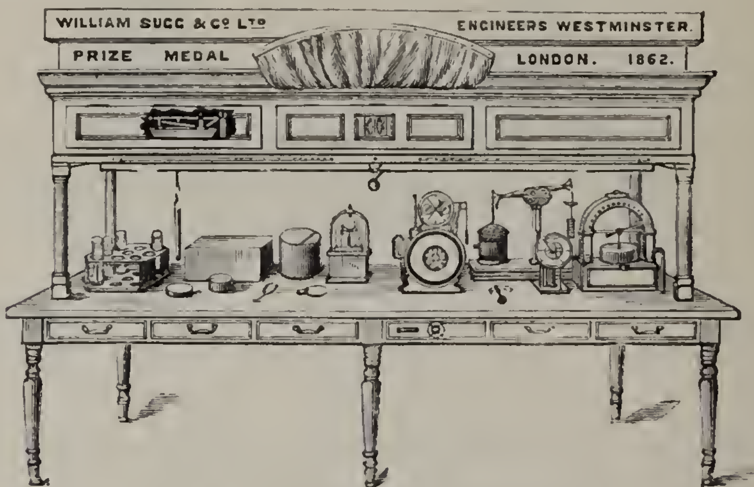


Fig. 5.—Closed Evans Photometer.

*The Closed Evans Photometers* was first introduced in 1858, under the following circumstances:—

In that year, in consequence of a dispute with the St. James's Vestry as to the illuminating power of the street lamps, it was decided to test the burners in use *in situ*, as the authorities at that time would not consent to the removal of the burners to a proper testing-room. Under the direction of Mr. F. J. Evans, then Engineer to The Gaslight and Coke Company, a closed Photometer was constructed, and

mounted on a platform in Piccadilly. The end of this Photometer was of such a size that it could be placed bodily over the street lamp. The disc was fixed at a point 50 inches from the flame; the candles were mounted on a travelling holder on the reverse side of the disc, and were moved for the purpose of taking the readings by means of an endless cord and winch-handle, situated immediately in front of the disc. Falling doors were fitted for affording access to the burner, disc, and candles respectively. As the testings had to be conducted in the open air, care was exercised to regulate the draughts to the gas and candles; and exit for the burnt gases was afforded by chimneys over the two ends of the box. This system evidently gave such satisfactory results to the inventor that, when he was appointed one of the Gas Referees under the Act of 1868, he so strongly advocated its use at the legal gas-testing stations that it was adopted, and first fixed at the Arundel Street, Leadenhall Street, Cannon Street, and Gray's Inn Lane testing-stations in 1869. The gas made at Bow Common was at the same time tested with an open Letheby Photometer at Friendly Place, Mile End Road; and it continued to be so tested until January, 1881, when this gas was tested with an Evans Photometer at No. 3, Jewry Street. Previous to this, however, the gas supplied by the City of London Gas Company, The Gaslight and Coke Company, and the Great Central Gas Company was, under the Act of 1860, carried into No. 37, Jewry Street, where the late Dr. Letheby tested the several supplies by an open bar Photometer from about 1862 to 1868. So that at this time there was by no means unanimity of opinion as to the respective merits of the two forms of apparatus. Since then, station

after station has been fitted indifferently with one or other of these instruments. In 1876, two stations prescribed by the Gas Referees were fitted with the open bar; but in 1878, in consequence of the complaints of the Company as to the low results obtained by the Official Examiner, the Gas Referees consented to the removal of these two Photometers, and the substitution of the Evans closed form in their place. The following are the average results obtained during 48 days before and 48 days after the alteration :—

| | Station A. | | Station B. |
|---|---|---|---|
| Before . . . . | 17·0 | .. | 16·1 Candles |
| After . . . . | 17·5 | .. | 17·1 ,, |

As originally constructed for the gas-testing stations, the Evans Photometer was ventilated by the two chimneys, one at either end. Subsequently objection was taken to the deficient ventilation thus afforded; and a long inverted box-cover, open downwards throughout the length of the instrument, was fitted in their place, with the view of ensuring more perfect exit for the products of combustion than had hitherto been obtained. For the same reason, the internal width of the box enclosing the flames and screen was enlarged. When, however, the new arrangement was applied to one of the existing forms, it immediately became apparent that a change for the worse had been made, as before the alteration somewhat reasonable results were obtainable; but afterwards it was almost impossible to get a test within 10 per cent. of the admitted value of the gas, and results of above 25 per cent. were by no means uncommon. The following series of tests recently made in rapid succession by no less than six of the most experienced

photometrists of the day, will show the utter unreliability of one of these converted old-pattern Evans Photometers :—

*Height of Gas-Flame, Three Inches.*

| Bunsen Disc. Candles. | | New Candles and Dibdin's Leeson Disc Candles. |
|---|---|---|
| 18·8 | 22·9 | 19·7 |
| 21·9 | 22·9 | 20·0 |
| 20·0 | 22·9 | 20·0 |
| 21·3 | — | — |

These were amongst some of the worst results given, but were by no means of uncommon occurrence.

For the purpose of thoroughly trying the question, the Author has at various times made careful comparison tests of three Evans Photometers with a simple bar Photometer used in the open without screens of any kind, other than those necessary to avoid errors due to reflection, and the protection of the observer from direct rays. The following are the results so obtained :—

| | | Evans Photometer. Candles. | Open Bar. Candles. |
|---|---|---|---|
| Evans Photometer No. 1 | First day | 16·0 | 16·3 |
| ,, | Second day | 16·5 | 16·4 |
| ,, | ,, | 15·3 | 15·3 |
| ,, | Third day | 17·2 | 17·3 |
| ,, | ,, | 16·8 | 16·0 |
| ,, | ,, | 18·0 | 16·0 |
| ,, | ,, | 17·6 | 16·6 |
| ,, | ,, | 16·0 | 16·5 |
| ,, | Fourth day | 16·3 | 16·2 |
| ,, | ,, | 16·8 | 15·5 |
| ,, | Fifth day | 16·3 | 15·9 |
| ,, | ,, | 16·7 | 16·2 |
| ,, | ,, | 17·0 | 16·0 |
| ,, | ,, | 17·5 | 16·5 |
| ,, | ,, | 15·7 | 14·2 |

| | | Evans Photometer. Candles. | Open bar. Candles. |
|---|---|---|---|
| Evans Photometer No. 2 | Sixth day | 17·3 | 17·3 |
| ,, | ,, | 18·5 | 17·1 |
| ,, | ,, | 16·6 | 17·1 |
| ,, | Seventh day | 17·1 | 16·3 |
| ,, | ,, | 16·9 | 16·7 |
| ,, | ,, | 17·2 | 16·3 |
| ,, | Eighth day | 16·4 | 15·7 |
| ,, | ,, | 17·1 | 17·2 |
| Evans Photometer No. 3 | Ninth day | 18·7 | 15·9 |
| ,, | ,, | 18·7 | 16·0 |
| ,, | ,, | 19·1 | 16·0 |
| ,, | ,, | 19·3 | 16·0 |
| ,, | ,, | 19·8 | 15·9 |
| ,, | ,, | 20·7 | 16·0 |
| ,, | Tenth day | 18·3 | 15·8 |
| ,, | ,, | 18·3 | 15·8 |
| ,, | ,, | 18·6 | 15·9 |
| ,, | ,, | 18·4 | 15·9 |
| ,, | ,, | 19·5 | 15·9 |
| ,, | ,, | 20·8 | 15·9 |
| Average | | 17·6 | 16·2 |

The average by the Evans was 1·4 candle over that indicated by the open bar. As the instrument No. 3 had afforded such high results, the Author conducted a special series of tests with that one, with the following results :—

*Evans Photometer No. 3, Wooden Top off, but Zinc Gauze Screens on.*

| | Evans. Candles. | Open Bar. Candles. | Height of Gas-Flame. |
|---|---|---|---|
| First day | 17·6 | 16·2 | 3 inches |
| ,, | 17·3 | 16·1 | ,, |
| ,, | 17·9 | 16·2 | ,, |
| ,, | 18·2 | 16·2 | ,, |
| ,, | 17·9 | 16·2 | ,, |
| ,, | 18·2 | 16·2 | ,, |

| | Evans. Candles. | | Open Bar. Candles. | | Height of Gas-Flame. |
|---|---|---|---|---|---|
| Second day . . | 16·3 | .. | 15·0 | .. | 3 inches |
| ,, . . . . | 16·6 | .. | 14·9 | .. | $2\frac{3}{4}$ inches |
| ,, . . . . | 16·9 | .. | 15·0 | .. | ,, |
| ,, . . . . | 17·2 | .. | 15·1 | .. | ,, |
| ,, . . . . | 17·4 | .. | 15·0 | .. | ,, |
| ,, . . . . | 17·5 | .. | 15·1 | .. | ,, |
| Third day . . | 17·0 | .. | 16·2 | .. | 3 inches |
| ,, . . . . | 17·4 | .. | 16·1 | .. | ,, |
| ,, . . . . | 17·7 | .. | 15·9 | .. | ,, |
| ,, . . . . | 17·9 | .. | 16·0 | . | ,, |
| ,, . . . . | 17·7 | .. | 16·1 | .. | ,, |
| ,, . . . . | 17·8 | .. | 16·1 | .. | ,, |
| Average . | 17·5 | .. | 15·8 | | |

The zinc gauze was next removed, so as to convert the Photometer into an open one, as far as possible; and the following results found :—

*Evans Photometer No. 3, with Wooden and Zinc Tops off.*

| | Evans Photometer. Candles. | | Open Bar. Candles. |
|---|---|---|---|
| | 15·6 | .. | 15·5 |
| | 15·4 | .. | 15·8 |
| | 15·7 | .. | 15·5 |
| | 16·3 | .. | 15·8 |
| | 15·6 | .. | 15·5 |
| | 15·6 | . | 15·8 |
| Average . | 15·7 | .. | 15·7 |

These results are only typical of a large number of others; one special series of over 90 having been conducted at the request of the Metropolitan Gas Referees, with the result of most fully endorsing the indications shown above as to the behaviour of Photometer No. 3—viz., that the removal of

the wooden top is a decided advantage. Previous to its removal, 19 and 20 candle gas was often indicated; while after its removal, these results fell to between 17 and 18 candles, and again dropped on the removal of the gauze screen to about 16 candles—the tests being far more concordant in the latter case. The errors due to candles were avoided as far as possible by the use of those of two diffeent makers and different packets.

In the course of a discussion on a paper read by the Author before The Gas Institute on June 14, 1888, Mr. C. Heisch said that—"He was free to confess that, until the Evans Photometers were introduced in the City testing-stations, he was not absolutely ignorant of their existence; but pretty nearly so. He had been in the habit of going all about the country testing gas; but never met with one out of the Metropolitan district. They were almost all open bars; and he believed an open bar was the best thing they could possibly use. Free ventilation, both of the candle (or whatever the standard might be) and of the gas, was obtained. Two objections to the Evans Photometer, besides its want of ventilation, were: (1) They looked at the disc through a pane of glass, which did not increase the facility of accurate reading; and (2) it was a temptation to a man to take a reading when his eyes were not in the best condition. He would sit in a light room, and just go under the hood, and take his observation; but if he waited (say) one or two minutes after getting under the hood, the observation would probably be different. With regard to the Evans Photometer, there seemed to him to be an idea that it invariably increased the apparent light of the gas, and diminished that of the standard; but he

happened to have in use two Photometers which had precisely the reverse effect—most distinctly depreciating the quality of the gas to a considerable extent. In order to be at all fair to the companies, he took off the bottom trough in which the cords ran, and sometimes the top cover; and he now obtained from the two Photometers very much the same results as he did with an open bar—which was almost invariably from 1 to 1½ candles higher than he could get before he took off the bottom. He thought this peculiar effect might be due to that circumstance; but, not being quite certain about it, he only threw it out as a suggestion. The disc-holder in the centre of the Photometer happened to fit very close indeed; so that both the heat and the carbonic acid generated principally at the gas end did not find their way beyond it. Therefore, the candles were, comparatively speaking, little affected—there being only a slight rise of temperature, whereas all the carbonic acid was collected on the gas side; and he believed it was this which had the depreciating effect. He mentioned this to show that the Evans Photometer did not always work in favour of the gas company."

*The Open Evans* was constructed in consequence of the foregoing remarkable experiments. The alterations consist in entirely removing the tops, both wooden case and the zinc gauze; cutting rectangular openings in the bottom of the box at each side of the gas-burner and the candles, and placing a sheet of perforated zinc underneath; fitting screens on either side of the disc-carrier to cut off reflected rays—the aperture in the screens having a knife edge; and replacing the old carrier with the new rotating holder. In this form, the instrument works very well, giving indications

of a reliable character. The gas-flame, which was before continually in an agitated condition, burns as steadily as in either the improved Letheby or the Imperial Photometer, presently to be described; and the increased steadiness of the candles is shown by the readings being fairly constant, instead of, as before, gradually increasing from (say) 8 to 10, which in itself was quite sufficient to condemn the instrument.

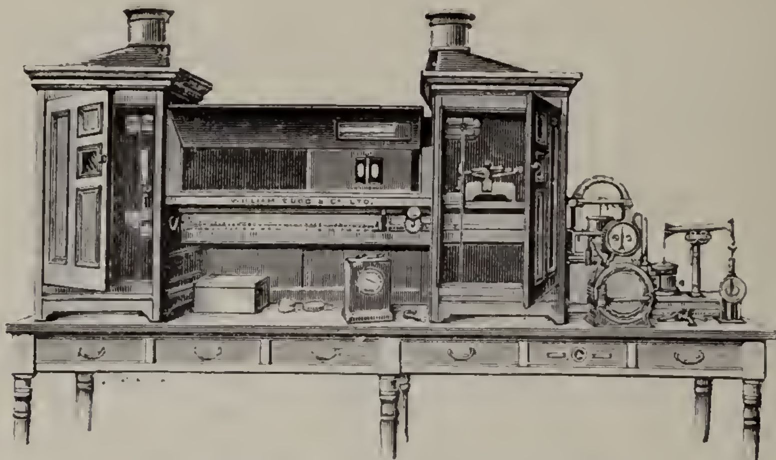

FIG. 6.—THE "IMPERIAL" PHOTOMETER.

*The "Imperial" Photometer.*—The following is Mr. Sugg's description of this Photometer, which is an outcome of a suggestion of Keates. It is complete in itself; and, like the well-known Evans Photometer, does not require that the room in which it is fixed shall be entirely dark, as with the Letheby and other "open" instruments.

The gas to be verified as to its illuminating power, and the candles used for the purpose, are burnt each in one of two square chambers or towers. In order that a large supply of fresh air may flow in such a tranquil stream as not in any way to disturb or shake the flames of either candles or

gas, it is taken from over the entire area of the bottom of the tower through a fine plate of perforated zinc. By this means they remain always rigid and still, as if they were cut out of paper, and can be aligned with the greatest ease and accuracy; whilst at the same time a more perfect change of air is secured than would be the case if they were allowed to burn in the open room without the surrounding chambers. The advantages of this arrangement will be especially appreciated in hot climates, and even in this country in summer weather.

The towers, standing on a bench, are separated from each other by the length of a graduated bar, made of white varnished pine (cut lengthwise of the grain), on which the calculated divisions of a 60-inch Photometer scale are inscribed. One of the extremities of this scale is immediately under the centre of the standard burner, and the other directly under a line drawn across, and at right angles with, the bar, cutting the centres of the flames of the two candles. Exactly parallel to this graduated bar, but nearer the top of the towers, two other bars, also of dry white varnished pine, are fixed one at the back and the other in front of the graduated bar. These serve to carry plumb-lines, which mark the exact position to be occupied by the gas-flame at one end and the candle-flames at the other, during an observation.

The standard in one tower on which the gas-burner is placed is rigidly fixed. The candle-balance, placed astride the end of the graduated bar in the other tower, is provided with an adjusting screw, enabling the operator to slide it backwards or forwards sufficiently to bring the centre of the flames always exactly 30 inches from the centre of the bar,

and thus to correct their tendency to get out of this their true position by the natural turning of the wicks as they burn.

The sighting-disc, with its mirrors fixed to it, is pivoted in a metal frame sliding in a metal groove at right angles with and across the Photometer bar, so that it can be easily drawn out and replaced when required. In addition to this, the disc and mirrors can be easily turned on their pivots, so as to bring the face of the disc looking towards the gas-flame in an exactly similar position with respect to the candles, and thereby enable the operator to correct any variation in the readings of the observed illuminating power due to any difference there may be in the two sides of the disc. The disc thus arranged astride the Photometer bar is enclosed by, and forms part of a chamber—the whole forming the sighting-box, as in the Letheby Photometer. This sighting-box is made to be moved smoothly, and by very small degrees if required, nearer to or farther from the candle end of the Photometer. This is done by means of a handle fixed on an arbor carrying a pinion, working into a larger wheel, fixed on to one end of a shaft, which drives an endless band attached to the disc chamber. The direct rays from both gas and candles on their way to the disc pass through openings in the corresponding ends of the disc chamber, of such size as to prevent any reflected rays from reaching the disc.

A curtain suspended from a canopy fixed over the head of the operator prevents the general light in the Photometer room from interfering with that received on the disc from the gas and candles in the Photometer. The scale of the Photometer bar is so placed with respect to the sighting-box that the readings cannot be seen by the operator while he is bringing

the disc into the position in which he considers the volume of light illuminating it to be equal on both sides; but as soon as he has formed his judgment, he can instantly illuminate the scale by opening a small door in the side of the gas tower nearest the disc. A small mirror fixed within the tower, at a proper angle with the gas-flame, projects a ray of light on another moveable mirror under the control of the observer. This enables him to direct the beam on to the scale, and also to obtain sufficient light to record the observation just made without leaving his place.

*Harcourt's Table Photometer.*—In a paper read before the Society of Arts on the 23rd of February, 1882, Professor Harold B. Dixon, F.R.S., exhibited and gave the following description of this new Photometer:—

"The method of comparing the illuminating power of two sources of light, by observing the distances at which the two lights must be placed from the screen, so that the portions illuminated by each shall be of equal brightness, was first adopted by Bouguer in 1729. Bouguer placed his lights behind a transparent screen, so arranged that one-half of it received the rays of one light only, and the other half the rays of the second light only, falling nearly perpendicularly on it. Exactly the same arrangement was afterwards adopted in his Photometer by Foucault, who employed for his transparent screen two sheets of glass, pressing a uniform layer of starch between them. Rumford, in 1792, addressed to the Royal Society a description of a Photometer, in which the two halves of a paper screen were severally illuminated by the rays of two lights falling at an angle of 60°. The observer sat facing the screen, with the two lights behind him, one on each side. Two small

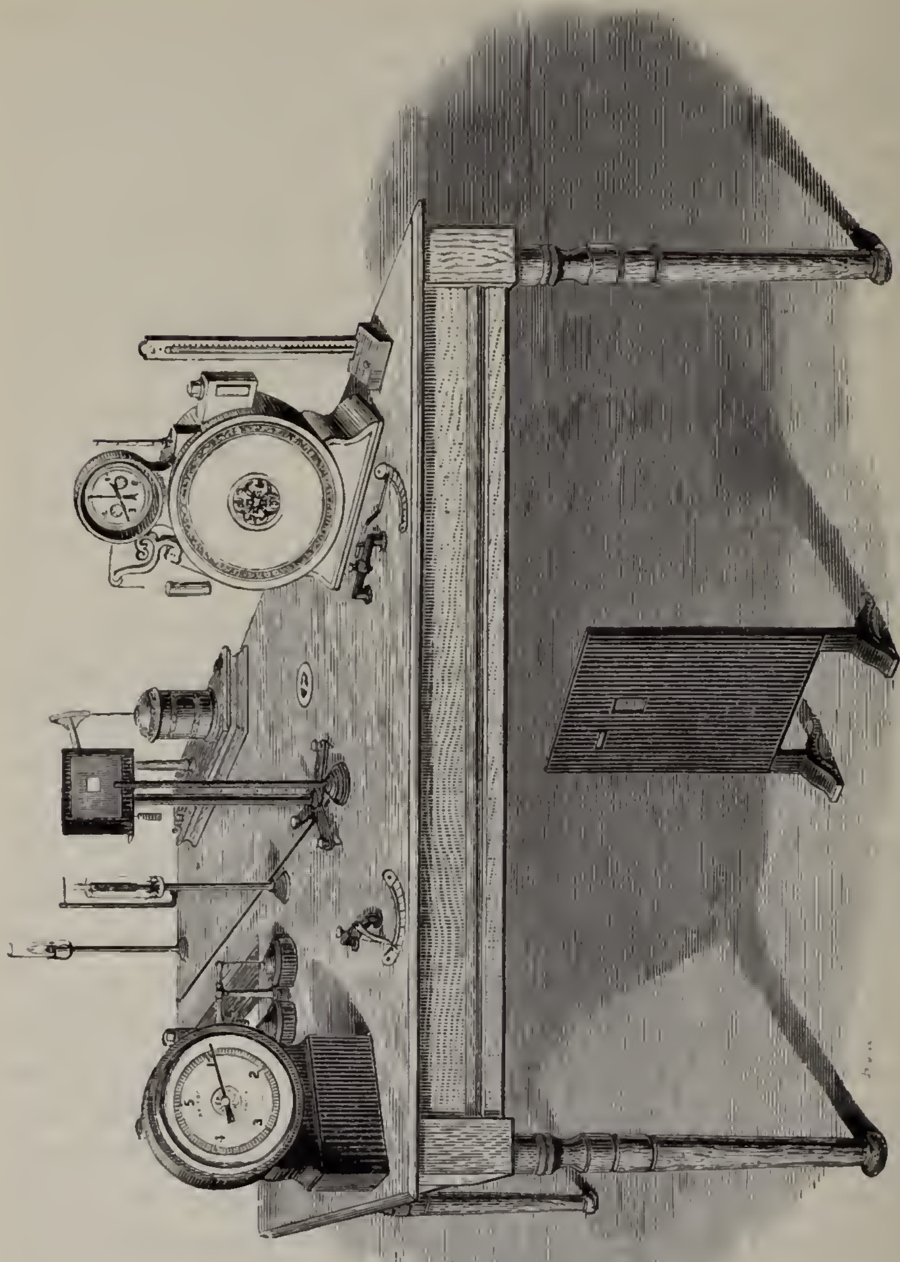

Fig. 7.—Harcourt's Table Photometer.

wooden uprights served to protect from the rays of one light that half of the screen illuminated by the rays of the other. Each upright had attached to it a supplementary strip of wood, which, by turning the upright round, could be brought to project into the light, and so increase the width of the shadow thrown on the screen. By this arrangement, the shadows thrown by each upright could be made to accurately coincide; and the eye had less difficulty in judging when the two portions of the screen were equally bright, because they then presented one homogeneously illuminated surface. Mr. Vernon Harcourt, in his new Photometer (which by his kindness I am able to exhibit for the first time this evening), has adopted a somewhat similar arrangement for his screen. The lights, as in Foucault's Photometer, are placed behind the screen, which is made of ordinary printing paper, No. 23, washed with water, and painted with a solution of spermaceti in petroleum. In front of the screen, and at a distance of about $\frac{3}{4}$ inch, is placed a brass diaphragm, having two similar vertical slits cut in it, side by side, at a distance apart equal to their own breadth. The two lights to be compared are similarly placed on each side of a line drawn perpendicular to the screen. Their rays fall at such an angle that the shadow thrown on the screen, owing to the solid piece between the two slits stopping the rays of one light, is exactly illuminated by the rays of the other light passing through one of the two slits. By adjusting the distance of the brass diaphragm from the screen, it is easy to make the shadows accurately coincide, so that when the central portion is as bright as the two outside portions, the screen presents one homogeneously illuminated surface."

In the Photometer represented on page 46, the standard pentane burner giving the light of one candle is shown fixed at a distance of 1 foot from the paper screen, and the standard Argand burner at a distance of 4 feet. The former is 2 inches to the left, and the latter 8 inches to the right, of a line perpendicular to the screen. A metal screen, in which two 1 inch by $\frac{1}{4}$ inch slots have been cut at a distance of $\frac{1}{4}$ inch apart, is so placed as to allow the light of the gas-flame to fall upon the paper through each slot, while that of the pentane passes through one slot and falls upon the shadow which is cast where the light from the gas is excluded by the partition between the slots. The observer sees only the transmitted light of the paper screen, through an opening 1 inch by $\frac{3}{4}$ inch in a black cloth, which obscures all other light. The pentane flame can be observed through another opening on a level with the top of that flame. Both burners having been lit, the pentane flame is raised until its tip touches, without passing, a piece of platinum wire stretched $2\frac{1}{2}$ inches above the burner. The observer then turns the gas-flame up or down until the surface of the paper is equally illuminated. He reads the position of the handle of the stopcock, which is so arranged as to move over about 2 inches of the graduated arc for a difference of consumption between 4·5 and 5·5 cubic feet. He then moves the handle. and again makes the illumination from the two sources equal, and takes a second reading, to which a third and fourth may be added if great accuracy is desired. Having then placed the handle of the stopcock in the mean position, he reads each meter—that through which pentane gas and that through which coal gas is passing—twice at intervals of a minute; both meters being placed conveniently for this

purpose. The corrected rate of consumption of the pentane gas should be nearly 0·5 cubic foot per hour, if both the making of the gas and the setting of the height of the flame have been rightly done. Its observation serves as a check upon these operations; but is not otherwise necessary. The amount which the gas-meter has gained or lost in two minutes, and the tabular number or reading of the Aërorthometer, give by a reference to a table the illuminating value of the gas."

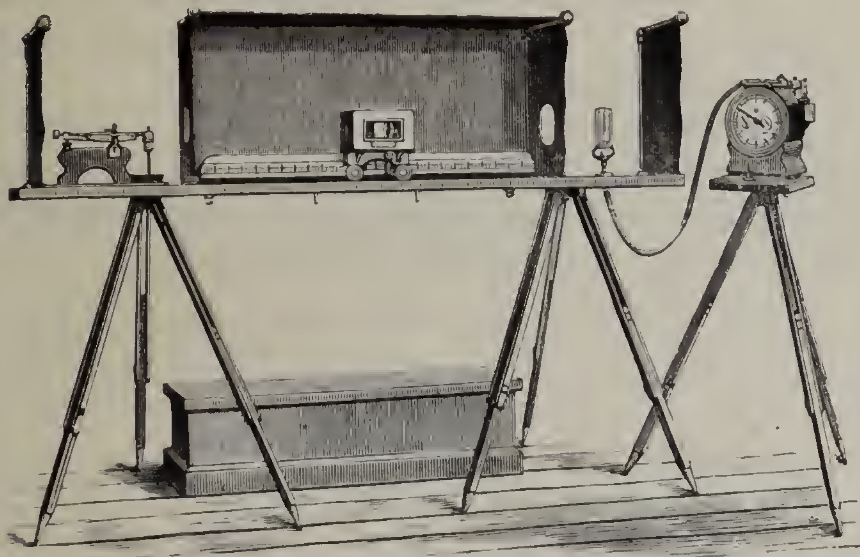

Fig. 8.—The Portable Photometer.

*The Portable Photometer* embraces all the essential points of the most approved pattern of the Letheby Photometer. It is easily taken to pieces, and packed in a box for conveyance; and is as readily set up again for use, with a little practice, in five minutes.

It comprises a 60-inch mahogany bar, inlaid with boxwood scale, and hinged in the centre; a sighting box, as used

by the Gas Referees; mahogany bench, clamped to prevent warping, and stained dull black; Keates's candle-balance, fixed by thumb-screws and peg to ensure its being at a proper distance from the bar. At the other end of the bar a Referees standard burner is fitted, with inlet arranged for a flexible metal tube with union joints, and supplied with a peg to ensure accurate adjustment. The table, which is provided with four supports, for black cloth curtains, is mounted on adjustable folding tripods.

The experimental wet meter, supported separately, shows the hourly rate of consumption by observations of one minute, or any quantity passed up to 1000 feet.

A double dry governor is fitted to the inlet of meter for adjusting pressure. The minute clock is fixed on top of the meter; and a micrometer adjustment is provided from the outlet of the meter to the inlet of the burner.

# CHAPTER III.

## "RADIAL" PHOTOMETERS.

THE recent introduction of the electric light, and of high-power gas-burners, for the improved illumination of open spaces and large areas generally, has inevitably led to a reconsideration of the methods in use for estimating the value of the various systems adopted.

It was formerly considered sufficient to estimate the intensity of the luminous rays in a horizontal direction only, irrespective of the value of those rays which are actually utilized in practice. Such a system was doubtless useful in those cases in which burners of similar primary construction were employed; but with the various forms of burners and lanterns recently introduced to the public, such a system is entirely erroneous, and can afford results of only a misleading character.

In order to ascertain the true value of a luminous agent, it is necessary to determine the power of those rays falling at angles, varying from the horizontal to the vertical, or, more strictly, through the whole of the semicircle, from the vertical line above to the vertical line below the point of illumination, thus—

FIG. 9.

For this purpose the ordinary form of Photometer is altogether unsuitable, and can be employed only after considerable modification, and with an expenditure of time and labour, which is all but out of the question. The Author has therefore devised an instrument of entirely different construction to the usual form, which renders the testing of the angular rays both easy and rapid.

Before proceeding to the description of this Photometer, it will be advisable to discuss the principles adopted, and the reasons for them.

When the Committee of the Gas Section of the International Gas and Electric Exhibition, held at the Crystal Palace in 1882-3, invited Professor William Foster and the Author to report upon the various burners exhibited, one of the first points considered by them, at the request of the Committee, was the estimation of the angular rays emitted from the various burners submitted to their examination.

*Hartley's "Universal" Photometer.*—For this purpose they employed a small portable Photometer, designed by Mr. F. W. Hartley, and termed by him the "Universal" Photometer. The instrument consists of a light narrow table, 11 inches wide, 2 feet 6 inches high, and 5 feet 6 inches in length. The scale is divided into inches and tenths, and is 21 inches in length. It is fitted into, and capable of being shifted and fixed at any position within, a groove in the table top, which has a long slot along its centre, below which slot is a brass socket connected by wire cords passing over pulleys to the winch handle, similar to the arrangement in the Evans Photometer, for moving the candles, and serving the same purpose—viz., the movement of the standard. The disc-carrier is supported on a stand,

the base of which is fitted with a pointer or index coinciding with the vertical line of the disc. The disc-carrier, like the scale, may be shifted along the table, and both must be moved at the same time; the index of the disc-carrier and the zero of the scale always being made to coincide with each other. With the Photometer a strong sliding pillar is provided, which, like the Photometer, stands upon the floor, and is fitted with levelling screws and plumb-lines. This pillar serves to carry gas-burners, or lamps of various sizes, as required. The apparatus, ready for use, is shown in Fig. 10 (next page). Mr. Hartley calculated a series of tables for use with the instrument, by means of which results are readily obtained.

As submitted to them, *the disc was rigidly fixed in the usual vertical position;* but at the Author's request, this was so arranged as to be susceptible of adjustment at any required angle, so that the rays from the standard and the burner under examination, whatever its position, might impinge upon the screen at equal angles. The following considerations will show the reasons for this:—

When two lights are opposed to each other in a horizontal direction, and a vertical screen is placed between them, it is evident that the rays impinging thereon must do so in accordance with the well-known law of the squares of the distance. If the actual distance of one of the lights from the screen remains constant while travelling through the circumference of a circle whose centre is coincident with the centre of the disc, the number of rays impinging upon the unit area of the disc must be less, and continue to decrease as the position of the light is increased from that of the horizontal line; and this decrease is in exact ratio

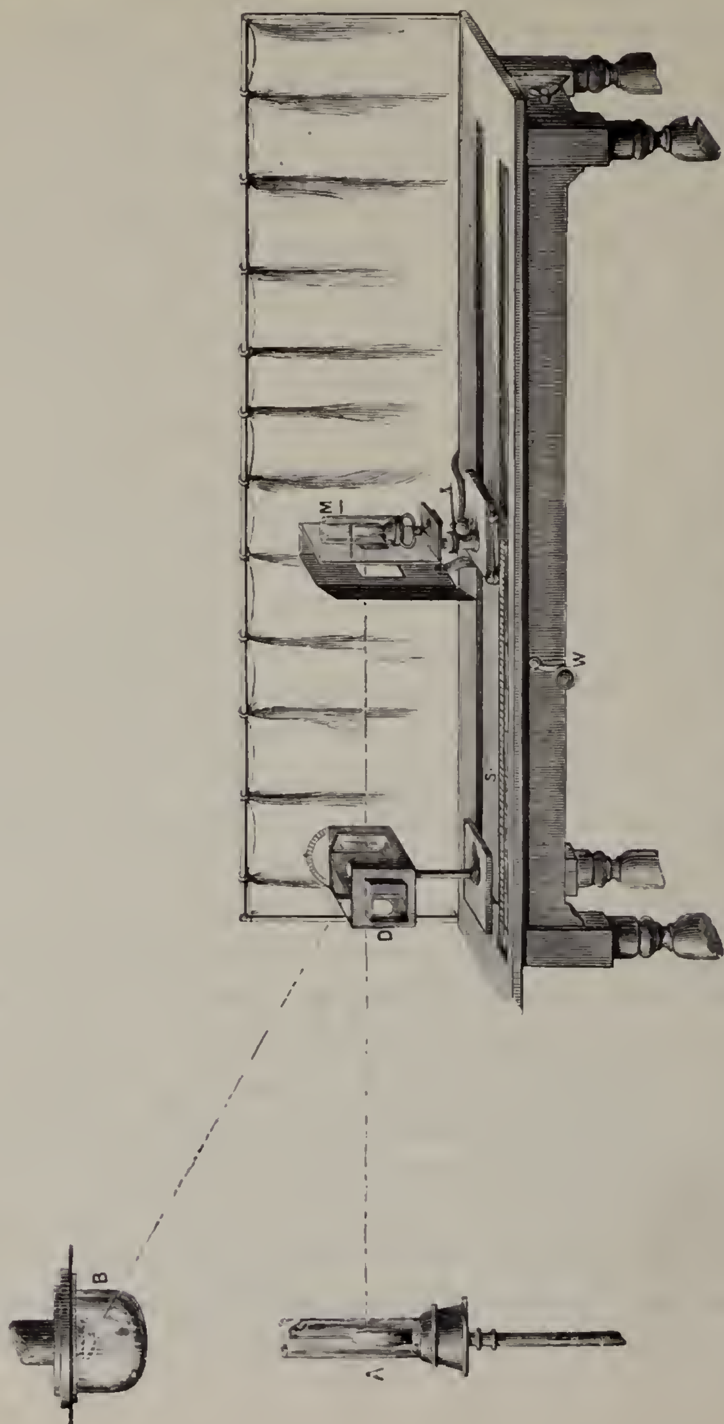


Fig. 10.—The "Universal" Photometer.

to the cosine of the angle formed by the position of the light with regard to the disc and the path of horizontal rays. Therefore, the number of rays impinging upon the vertical disc will diminish with the cosine of the angle thus formed.

The following diagram (Fig. 11) shows this very clearly:—

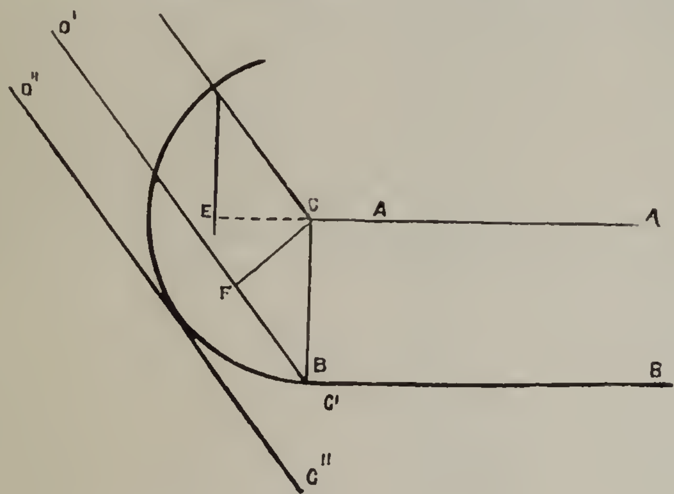


Fig. 11.

Let AA¹ BB¹ represent the section of horizontal rays impinging at right angles upon the vertical disc CC¹, and CD, C¹¹D¹¹ the section of an equal number of rays thrown at a downward angle from a source of light placed above the horizontal. It is evident that the whole of the angular rays do not impinge upon the disc CC¹, but that the rays which do so are defined by CD, C¹D¹. By drawing the circumference of a circle whose radius is CC¹, and finding the cosine CE, it is at once seen that the section of the rays CF, which impinge upon the disc, is in exact proportion to the cosine of the angle of incidence CE.

When the light is raised throughout a quadrant, the

number of rays impinging upon the vertical disc will be *nil*; and thus, although the burner may be one of high illuminating power, such a system of Photometry would fail to record any value for it.

Another important point in connection with the vertical disc must not be overlooked, and that is that, when the rays of light impinge upon a surface at an oblique angle, a considerable loss of light occurs by reason of the increase of reflection and absorption, which preponderates over the loss incurred when the angle of incidence forms a right angle. This loss increases with the increase of the angle, and seriously vitiates any results obtained. The Table on the next and succeeding pages shows the results of some tests made in this manner.

TABLE

*Showing the Illuminating Power of "Angular Rays" when tested with the Photometer Disc fixed in a vertical position, and when it is arranged so that the angles of incidence are identical:—*

*Rays from Burner 22·5° with Horizontal Line.*

| Readings with Disc Vertical. | Corrected for Cosine of Angle=0·9239. | Readings with Disc arranged for equal Angles of Incidence. | Loss p.c. by Estimation with Vertical Disc due to Reflection. |
|---|---|---|---|
| 38·7 .. | 41·9 .. | 44·1 .. | 4·9 |
| 205·0 .. | 222·0 .. | 245·0 .. | 9·4 |
| 453·5 .. | 491·0 .. | 519·5 .. | 5·5 |
| 27·0 .. | 29·2 .. | 29·7 .. | 1·6 |
| 326·0 .. | 353·0 .. | 352·0 .. | — |
| 62·8 .. | 68·0 .. | 68·8 .. | 1·1 |
| 26·5 .. | 28·7 .. | 30·8 .. | 6·8 |
| 140·5 .. | 152·1 .. | 162·2 .. | 6·1 |
| | | Average . . . . | 4·4 |

*Rays from Burners 45° with Horizontal Line.* *Cosine* = 0·7071.

| Readings with Disc Vertical. | Corrected for Cosine of Angle=0·7071. | Readings with Disc arranged for equal Angles of Incidence. | Loss p.c. by Estimation with Vertical Disc due to Reflection. |
|---|---|---|---|
| 20·2 .. | 28·6 .. | 34·9 .. | 18·0 |
| 282·5 .. | 400·0 .. | 491·5 .. | 18·6 |
| 20·6 .. | 29·2 .. | 34·2 .. | 14·6 |
| 47·5 .. | 67·2 .. | 87·3 .. | 22·0 |
| 23·7 .. | 33·6 .. | 38·4 .. | 12·5 |
| 49·4 .. | 70·0 .. | 85·8 .. | 18·4 |
| 42·5 .. | 60·2 .. | 67·1 .. | 10·3 |
| 15·6 .. | 22·1 .. | 25·2 .. | 12·3 |
| 81·0 .. | 114·8 .. | 136·5 .. | 15·9 |
| 124·1 .. | 176·0 .. | 186·9 .. | 15·8 |
| 104·2 .. | 147·8 .. | 161·9 .. | 8·7 |
| 15·7 .. | 22·2 .. | 25·1 .. | 11·6 |
| 88·2 .. | 125·0 .. | 144·0 .. | 13·2 |
| 14·5 .. | 25·5 .. | 25·7 .. | 0·8 |
| 9·2 .. | 13·0 .. | 12·7 .. | — |
| 129·3 .. | 183·0 .. | 207·0 .. | 11·6 |
| 9·0 .. | 12·7 .. | 12·6 .. | — |
| 52·2 .. | 74·0 .. | 86·5 .. | 14·5 |
| | | Average. . . . | 12·15 |

*Rays from Burner* 67·5° *with Horizontal Line.* *Cosine*=0·3827.

| Readings with Disc Vertical. | | Corrected for Cosine of Angle=0·3827. | | Readings with Disc arranged for equal Angles of Incidence. | | Loss p.c. by estimation with Vertical Disc due to Reflection. |
|---|---|---|---|---|---|---|
| 55·3 | .. | 144·5 | .. | 378·0 | .. | 61·8 |
| 82·8 | .. | 216·5 | .. | 920·0 | .. | 76·5 |
| | | | | Average | . . . | 69·1 |

After correction for the diminished number of rays impinging upon the disc at the different angles, the value obtained is deducted from that found by estimation with the disc arranged for equal angles of incidence, and the difference between the two results calculated into percentages. By this means the Author finds that, when the burner is at an

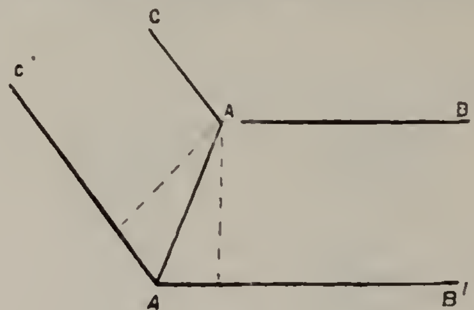


Fig. 12.

angle of 22·5° above the horizontal, the average loss due to reflection from the vertical disc is 4·4 per cent.; at 45°, it is 12 per cent.; and at 67·5°, 69 per cent.

It is obvious, therefore, that the method of estimating the illuminating power of angular rays by means of a vertical disc is erroneous.

By arranging the disc so that the angle of incidence is equal on either side, thus (disc, $AA^1$; horizontal rays, $AB$, $A^1B^1$; angular rays, $CA$, $C^1A^1$), we equalize both the proportionate number of rays impinging thereon, as well as

the loss due to reflection. Determinations thus made possess all the value of those made with a vertical disc and horizontal rays on either side in the usual manner.

*The Radial Photometer.*—The principle involved in the construction of the Radial Photometer is very simple—viz., that the light under examination should be rigidly fixed in one position while the estimations of the value of the angular rays emitted from the horizontal to the vertical, either above or below, are being made; thus ensuring perfect steadiness of the burner, or other luminous point.

The apparatus consists of two vertical supports, one of which is permanently fixed to the base-board or foot, while the one on the right hand travels on rollers on the base-board in such a position that it will run in front of the fixed support.

The two uprights are connected by a bar, the ends of which work upon trunnions or axles attached to blocks, which travel in the grooves of the uprights. These blocks can be clamped in any desired position. One end of the bar is attached to the front of the fixed upright, while the other end is attached to the travelling upright at the back; so that, when the two uprights are in juxtaposition, the bar is perpendicular between them. The centres of the trunnions correspond in position with the centres of the two graduated dial plates in front of the uprights. The distance between the centres of these dial plates is 50 inches. It is therefore evident that, whatever *position* the bar may be in, the *distance* from the centre of one dial to that of the other must be constant. In front of the dial plate on the travelling upright the screen or disc-holder is fixed, so that its centre is coincident with the centre of the dial.

Attached to the block in the groove of the travelling upright support is the horizontal bar carrying the standard. The standard is supported in front of the horizontal bar by a travelling carriage, working on rollers, and is moved by a cord and winch, conveniently placed on the right-hand side of the graduated dial on the support. Attached to the block carrying the Photometer disc is a brass rod, which is brought well forward, and then curved round for the purpose of carrying a velvet curtain to screen off extraneous light when readings are being taken.

The two dial plates are graduated—the larger one on the fixed support in degrees, and the smaller one on the travelling support in half degrees, which are numbered as whole degrees for the purpose of facilitating the setting of the disc for equal angles of incidence; so that when the bar is set (say) at 40°, the disc-pointer is to be set at 40°. It will then be in the proper position—viz., 20°. The disc may be arranged to work automatically with the movement of the bar, by means of a simple mechanical appliance; so that, whatever may be the position of the bar, the disc will be at the correct angle.

A brass rod is provided for adjusting the position of the burner, &c., to be tested. It has to be pushed through the centre of the block and trunnion on the fixed upright support, and will then be at right angles with the plane of the dial, and project exactly through its centre, by which means it is easy to fix the exact position of the flame in front of the apparatus. The light to be tested may be brought forward to the full extent that can be attained by the disc and standard, which, obviously, can be regulated as desired, so that the size of the burner or lantern to be

tested by this apparatus is practically unlimited, due regard being paid to the length of the bar and the power of the light.

When a test is commenced, the light to be examined is fixed on the support attached to the block in the fixed upright, and accurately centred with the dial plate, which is to be lowered to the bottom of the groove in the support. The block in the travelling support has next to be raised, which operation will bring it immediately over the burner; the travelling upright being in front of the fixed support, and the pointer on the bar indicating 90° on the large dial-plate. The Photometer disc is to be arranged for equal angles of incidence, by turning it until its pointer is at 90, when a reading can be taken. The clamp holding the top

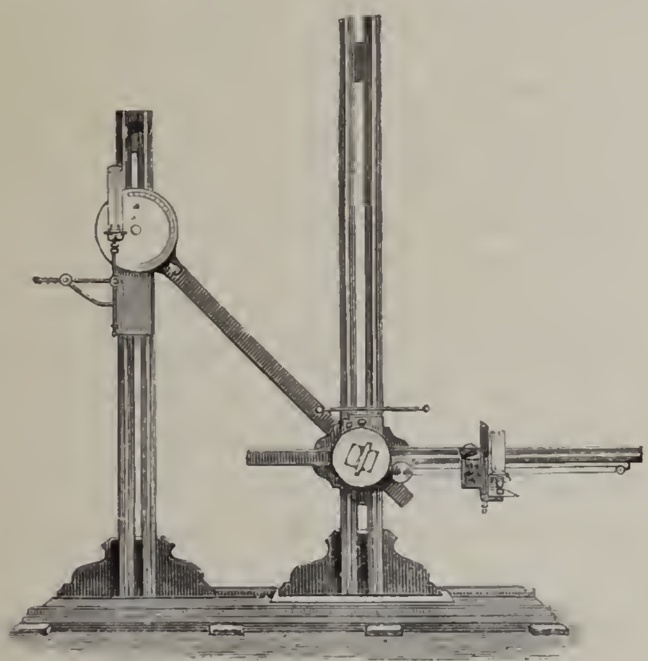

FIG. 13.—THE RADIAL PHOTOMETER.

block in position is then loosened, and the handle working the rack and pinion of the travelling support turned until the bar is at an angle of 80°. The block must then be clamped, the disc adjusted to 80, and so on for each degree or ten degrees as desired, until the horizontal rays are estimated. The block supporting the light is then to be raised to the higher position, and the bar adjusted for the desired angle below the horizontal, and a second series of readings taken until the downward vertical rays are estimated. Fig. 13 shows the instrument arranged for testing the rays thrown downward at an angle of 45°.

It is to be hoped that in future all comparative tests of the value of various burners will be so conducted as to show the actual work done by them, not only in one direction, but in all directions. With Argand and other circular burners, this can be done by making one series of tests from the vertical above to the vertical below, at every 10 degrees. But in the case of flat-flame burners, it is necessary that this series should be made in duplicate, one with the flame flat, or at right angles to the bar of the Photometer, and one with the flame placed with its edge to the bar. An extensive series of experiments on this point has shown that very considerable differences exist between the quantity of light emitted from the flat surface and from the edge of various burners; this difference varying from 10 to 35 per cent. of the light emitted from the flat surface. Therefore, it is very necessary that the two series of tests should be made, and an average taken, which should be held to represent the value of the burner.

For the purpose of facilitating comparison, the Author has made determinations of the quantity of light afforded

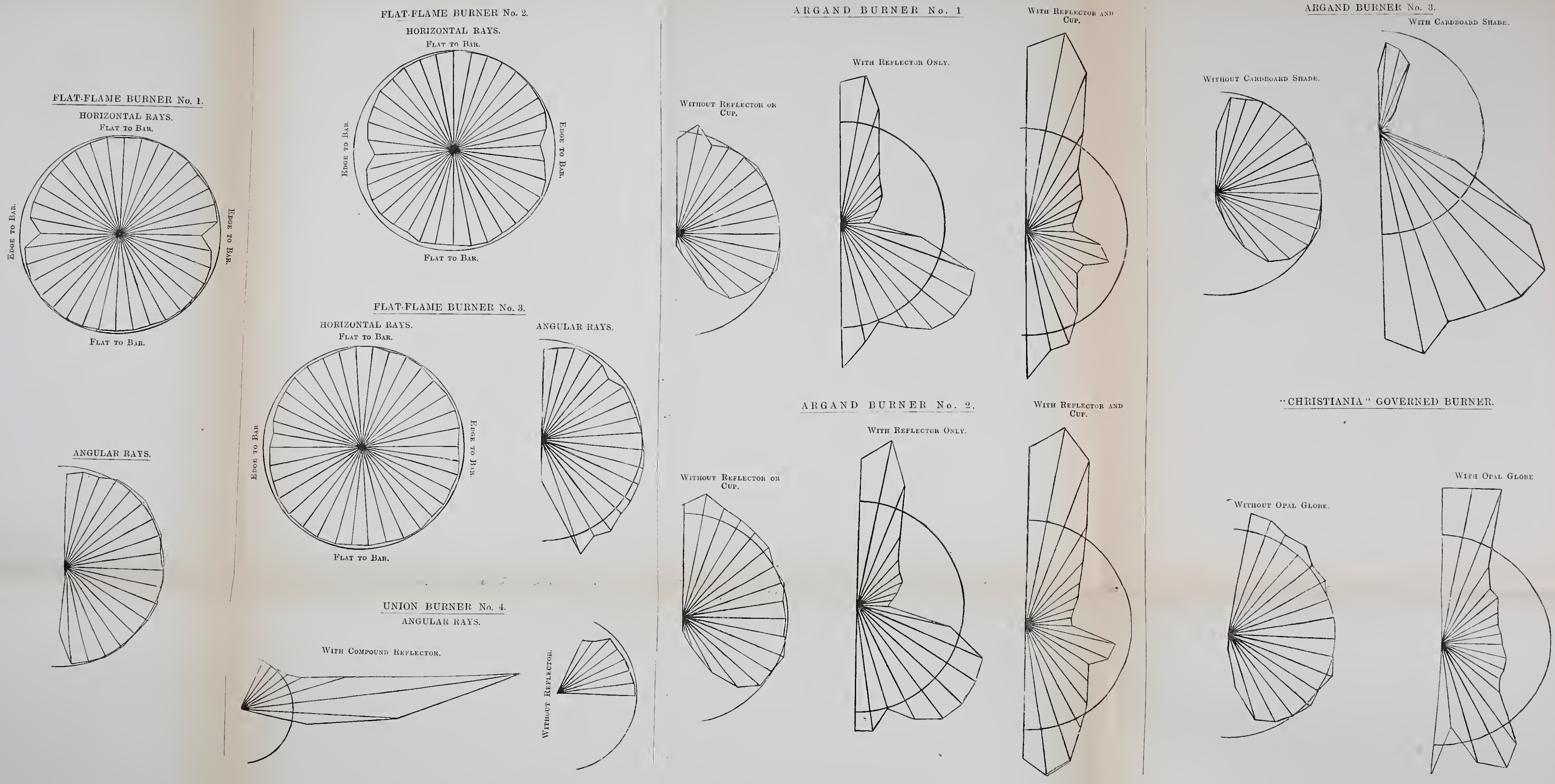


PLATE No. 2 (see p. 63).

in all directions horizontally by three classes of flames, testing them at every 10°. The results are stated in Table I., p. 65. The diagrams (Plate II.) show at a glance the positions in which the maximum light is thrown.

The value of the Radial Photometer is most strikingly shown in the examination of burners shaded by globes, reflectors, &c. For this purpose the Author has tested three Argand burners, fitted with different forms of shades. Table III., p. 67, contains the results, which are also put in diagram form. Two of these sets of observations clearly indicate that the form of the porcelain cup might be arranged to yield more satisfactory results, but considering the want of a suitable method of testing, before the Radial Photometer was introduced, there is little room for complaint. The effect of the well-known glazed-paper shade is very striking; the even distribution of light downward being very satisfactory. The tests of a Christiania burner, with and without its globe, are also interesting; but, as in this case the globe has to do the double duty of regulating the draught and reflecting the rays in a downward direction, it is difficult to see how its form can be improved. The tests of a new form of reflector well illustrate the character of the work of which the Radial is capable. The tests may be taken at every degree where necessary, and thus most valuable comparative results are obtained.

The effect of a suitable reflector in diffusing the power of the light in particular directions is very marked; so much so, that in future competitive tests of burners and apparatus relating thereto, it would be highly desirable to make special awards for the best form and diffusing power of reflectors. In the Author's judgment, the most perfect reflector should

throw the rays of light in such a manner as to evenly illuminate a level surface comprised within a circle whose circumference includes those rays falling at an angle of 30° below the horizontal.

The nearest approximation to this definition is the result given by the well-known porcelain shade supplied with Argand burners. When the cup is in position, the rays, falling at all angles from 0° to 60° below the horizontal, are intercepted to an excessive extent.

The importance of facility in testing a new disc for photometric readings is generally acknowledged. The form of carrier used with the Radial Photometer is especially adapted for readily adjusting the disc, so that either side may be turned towards the standard light. It is only necessary to loosen the screw holding the carrier, when the latter can be rotated on its axis. It may be of interest to point out that this is the first Photometer to which the Author's rotating disc-holder, now coming into very general use, was applied.

TABLE I.

*Flat-Flame Burners. Illuminating Power of Horizontal Rays.*

| Position of Flame. | | | | Burner No. 1 Candles. | Burner No. 2 Candles. | Burner No. 3 Candles. |
|---|---|---|---|---|---|---|
| Flat to Photometer Bar | | | . | 30·8 | 24·2 | 8·5 |
| Flame Turned | | . | 10° | 30·8 | 24·2 | 8·5 |
| | ,, | ,, . | 20 | 30·9 | 24·3 | 8·5 |
| | ,, | ,, . | 30 | 30·9 | 24·2 | 8·5 |
| | ,, | ,, . | 40 | 30·8 | 24·0 | 8·4 |
| | ,, | ,, . | 50 | 30·2 | 24·0 | 8·3 |
| | ,, | ,, . | 60 | 30·1 | 23·8 | 8·2 |
| | ,, | ,, . | 70 | 30·2 | 23·5 | 8·2 |
| | ,, | ,, . | 80 | 29·8 | 22·4 | 8·2 |
| Edge to Bar | ,, | ,, . | 90 | 24·4 | 20·3 | 7·9 |
| | ,, | ,, . | 100 | 28·7 | 21·6 | 8·2 |
| | ,, | ,, . | 110 | 29·6 | 22·8 | 8·3 |
| | ,, | ,, . | 120 | 30·3 | 23·5 | 8·3 |
| | ,, | ,, . | 130 | 30·5 | 23·4 | 8·3 |
| | ,, | ,, . | 140 | 30·5 | 23·2 | 8·3 |
| | ,, | ,, . | 150 | 30·5 | 23·4 | 8·4 |
| | ,, | ,, . | 160 | 30·1 | 23·5 | 8·4 |
| | ,, | ,, . | 170 | 30·4 | 23·2 | 8·3 |
| Flat to Bar | ,, | ,, . | 180 | 30·3 | 23·1 | 8·4 |
| | ,, | ,, . | 190 | 30·4 | 22·8 | 8·4 |
| | ,, | ,, . | 200 | 30·8 | 23·0 | 8·4 |
| | ,, | ,, . | 210 | 30·8 | 22·7 | 8·4 |
| | ,, | ,, . | 220 | 30·7 | 22·9 | 8·3 |
| | ,, | ,, . | 230 | 31·0 | 22·9 | 8·3 |
| | ,, | ,, . | 240 | 30·6 | 22·8 | 8·3 |
| | ,, | ,, . | 250 | 30·1 | 22·0 | 8·2 |
| | ,, | ,, . | 260 | 29·5 | 21·2 | 8·1 |
| Edge to Bar | ,, | ,, . | 270 | 25·0 | 18·6 | 7·8 |
| | ,, | ,, . | 280 | 28·5 | 20·6 | 7·8 |
| | ,, | ,, . | 290 | 29·5 | 21·9 | 8·1 |
| | ,, | ,, . | 300 | 29·7 | 22·2 | 8·3 |
| | ,, | ,, . | 310 | 29·8 | 23·0 | 8·3 |
| | ,, | ,, . | 320 | 30·3 | 23·0 | 8·4 |
| | ,, | ,, . | 330 | 30·3 | 23·5 | 8·3 |
| | ,, | ,, . | 340 | 30·5 | 23·4 | 8·4 |
| | ,, | ,, . | 350 | 30·7 | 23·5 | 8·4 |
| Flat to Bar | ,, | ,, . | 360 | 30·9 | 23·4 | 8·5 |

### Table II.

*Flat-Flame Burners. Illuminating Power of Angular Rays.*

| Direction of Rays. | Burner No. 1 Candles. | Burner No. 2 Candles. |
|---|---|---|
| 90° above horizontal . . . . . . | 27·8 | 8·9 |
| 80 ,, ,, . . . . . . | 29·2 | 9·0 |
| 70 ,, ,, . . . . . . | 29·0 | 9·3 |
| 60 ,, ,, . . . . . . | 30·5 | 9·3 |
| 50 ,, ,, . . . . . . | 30·8 | 9·2 |
| 40 ,, ,, . . . . . . | 30·9 | 8·7 |
| 30 ,, ,, . . . . . . | 30·3 | 9·4 |
| 20 ,, ,, . . . . . . | 30·4 | 9·3 |
| 10 ,, ,, . . . . . . | 29·4 | 9·3 |
| Horizontal . . . . . . . . . | 29·8 | 9·7 |
| 10° below horizontal . . . . . . | 29·9 | 9·9 |
| 20 ,, ,, . . . . . . | 30·2 | 10·0 |
| 30 ,, ,, . . . . . . | 30·2 | 10·1 |
| 40 ,, ,, . . . . . . | 29·8 | 10·0 |
| 50 ,, ,, . . . . . . | 29·8 | 10·0 |
| 60 ,, ,, . . . . . . | 30·0 | 10·7 |
| 70 ,, ,, . . . . . . | 29·2 | 10·3 |
| 80 ,, ,, . . . . . . | 28·7 | 11·2 |
| 90 ,, ,, . . . . . . | 19·6 | 5·8 |

## TABLE III.

*Effect of Reflectors and Shades.*

| Direction of Rays. | Argand No. 1. | | | Argand No. 2. | | | Argand No. 3. | | Christiania. | | Union. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Without Shade, &c. | With Reflector only. | With Reflector and Cup. | Without Shade, &c. | With Reflector only. | With Reflector and Cup. | Without Shade, &c. | With Paper Reflector. | Without Globe. | With Globe. | Without Reflector. | With Compound Reflector. |
| 90° above horizontal | 16·8 | 27·6 | 33·0 | 19·0 | 25·0 | 29·0 | 10·6 | 9·3 | ... | 17·6 | ... | ... |
| 80 ,, ,, | 20·0 | 30·8 | 36·6 | 21·0 | 29·0 | 33·0 | 14·0 | 13·7 | 14·0 | 18·4 | ... | ... |
| 70 ,, ,, | 17·4 | 24·4 | 31·2 | 19·4 | 21·4 | 28·4 | 14·2 | 12·9 | 14·1 | 19·3 | 8·7 | 9·2 |
| 60 ,, ,, | 18·2 | 14·8 | 21·0 | 18·8 | 13·8 | 19·2 | 15·0 | 11·0 | 13·4 | 10·3 | 8·7 | 9·2 |
| 50 ,, ,, | 18·6 | 11·2 | 14·8 | 18·8 | 10·0 | 14·0 | 15·0 | 4·0 | 13·6 | 8·4 | 8·7 | 9·8 |
| 40 ,, ,, | 18·8 | 9·8 | 12·8 | 18·4 | 8·4 | 11·0 | 15·1 | 1·3 | 12·8 | 8·0 | 8·6 | 10·4 |
| 30 ,, ,, | 18·6 | 9·0 | 11·8 | 17·0 | 7·8 | 9·2 | 15·1 | 1·3 | 13·0 | 7·0 | 8·7 | 12·6 |
| 20 ,, ,, | 18·6 | 7·6 | 10·1 | 17·2 | 6·4 | 8·4 | 15·0 | 2·0 | 12·4 | 6·5 | 8·8 | 19·6 |
| 10 ,, ,, | 18·6 | 6·2 | 8·8 | 16·8 | 5·4 | 7·2 | 15·0 | 1·0 | 12·3 | 6·7 | 7·2 | 50·0 |
| Horizontal | 18·6 | 5·2 | 8·6 | 16·8 | 4·8 | 7·6 | 15·0 | 0·0 | 12·2 | 7·0 | 6·6 | 28·0 |
| 10° below horizontal | 18·8 | 14·4 | 13·8 | 17·2 | 16·0 | 15·0 | 15·6 | 2·0 | 12·3 | 7·6 | ... | ... |
| 20 ,, ,, | 19·2 | 24·2 | 15·6 | 17·8 | 21·6 | 14·2 | 15·8 | 12·5 | 13·0 | 7·6 | ... | ... |
| 30 ,, ,, | 18·2 | 25·6 | 12·2 | 17·2 | 23·0 | 12·0 | 15·6 | 25·4 | 12·7 | 8·0 | ... | ... |
| 40 ,, ,, | 16·4 | 26·0 | 11·8 | 16·8 | 23·4 | 13·4 | 14·0 | 31·0 | 12·8 | 9·0 | ... | ... |
| 50 ,, ,, | 15·2 | 24·8 | 13·2 | 14·4 | 23·4 | 16·2 | 12·3 | 30·8 | 12·3 | 15·0 | ... | ... |
| 60 ,, ,, | 11·2 | 22·0 | 17·4 | 11·0 | 20·0 | 19·4 | 8·4 | 30·0 | 11·6 | 17·2 | ... | ... |
| 70 ,, ,, | 6·0 | 18·8 | 20·8 | 6·2 | 17·0 | 23·4 | 4·8 | 29·4 | 10·8 | 15·1 | .. | ... |
| 80 ,, ,, | 2·6 | 21·2 | 21·8 | 4·0 | 20·8 | 25·2 | 2·5 | 33·0 | 6·3 | 10·3 | ... | ... |
| 90 ,, ,, | 2·0 | 25·6 | 26·6 | 2·0 | 20·2 | 23·6 | 1·0 | 30·4 | 1·6 | 7·0 | ... | ... |
| Average | 15·46 | ... | ... | 15·26 | ... | ... | 12·31 | ... | 11·73 | ... | ... | ... |

*Sugg's "Travelling" Photometer.*—In this Photometer, which has been erroneously confounded with the Author's "Portable" Photometer, the standard of light used for comparison is a Keates lamp, burning sperm oil, provided with a Methven slit placed across the flame of the burner, instead of vertically as in the

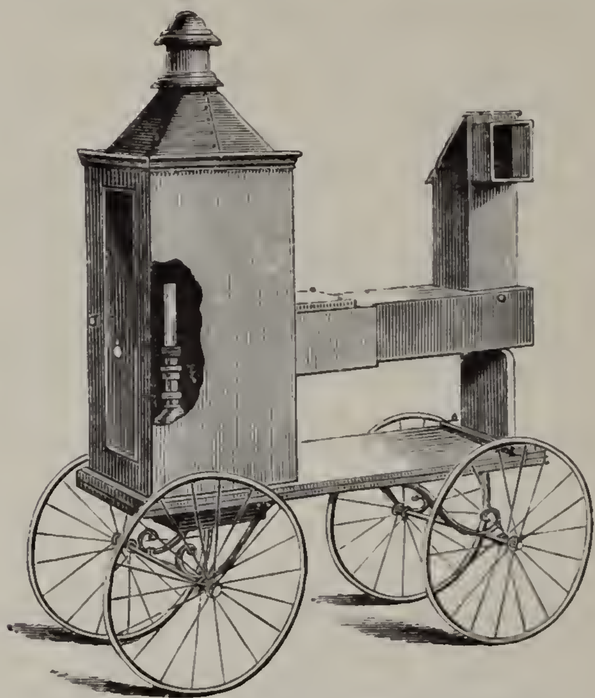

FIG. 14.—SUGG'S TRAVELLING PHOTOMETER.

Methven standard of light. The slit is of such size as to allow a portion of the whole light of the lamp equal to that of two candles to pass through it. This standard light, which is constant, is enclosed in a dark chamber properly ventilated; the front part of the chamber communicating, by means of a square wooden tube, with one

side of the comparison disc. This disc is shaped like the letter **A**, and covered on both sides with white paper. A newspaper cutting is then pasted over the edge of the disc, so that a portion of the print is on each side of it. The two sides are separated by means of a partition, which is carried up some distance above the discs. One side—that nearer the lamp—is covered so that no other light but that of the lamp can fall upon it; the other side is left open to receive the full light from the electric or other light to be examined. A mirror properly placed enables the observer to see both sides of the disc at once, and thus to judge of the relative amount of light falling on each. The standard degree of light adopted is therefore equal to that which will fall on a white surface from the rays of 2 candles placed at a distance of 3 feet from that surface. The Photometer as thus used is on the Church and Mann principle; but it may be arranged on the King principle, and thus be used to measure the amount of light falling in any part of a roadway at a distance of 3 feet from the ground.

*The Holophotometer.*—The following description of this photometer is extracted from the *Journal of Gas Lighting*, July 17, 1888:—

Fig. 15 is a view of this instrument from behind, showing the divided scale; fig. 16 is a view taken from the end of the Photometer-bar, showing how the horizontal light from the lamp is transmitted to the disc; and fig. 17 is a view taken looking from the disc, and showing how the vertical light would be transmitted to the disc.

The Holophotometer has been designed in order to get rid of two difficulties connected with other methods of attaining

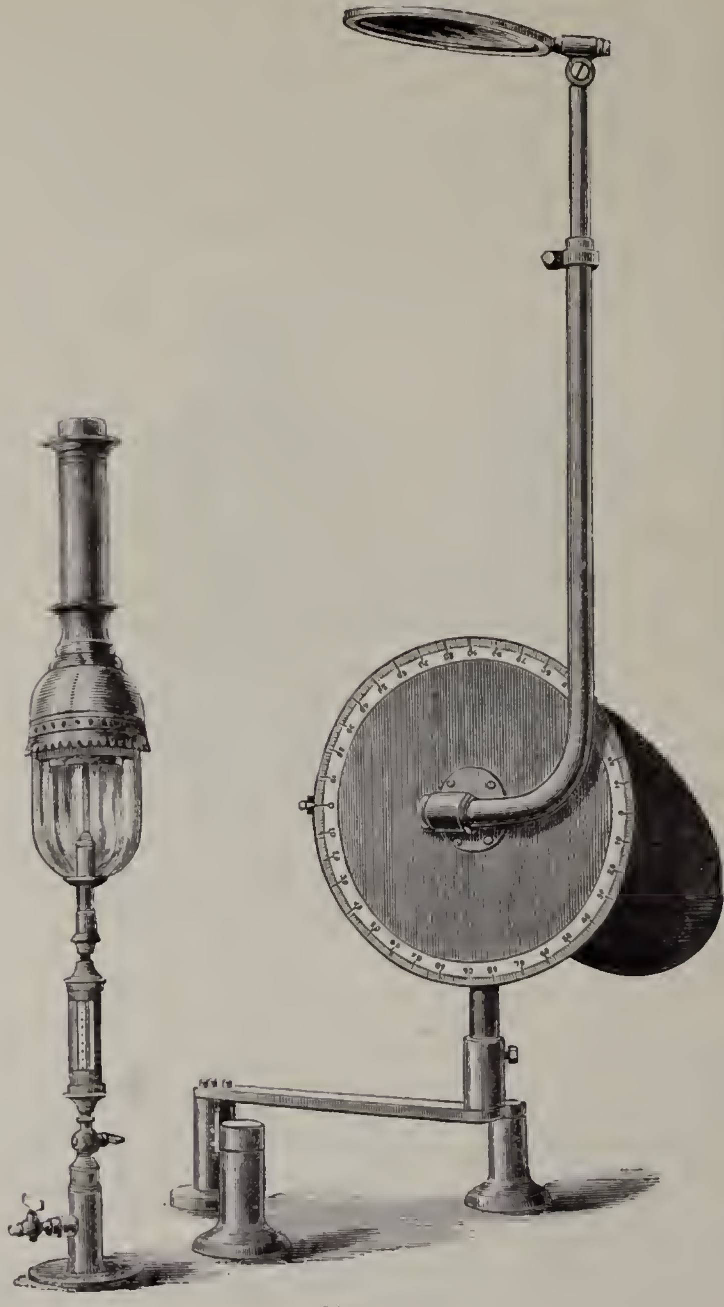

Fig. 15.

the same object—viz., to measure the light emitted in every direction by any luminous source. These difficulties are: (1) The movement of the light to be measured or of the standard lamp, neither of which is desirable. (2) The errors caused in the measurement of lamps provided with reflecting fittings, by the assumption that the flame is the

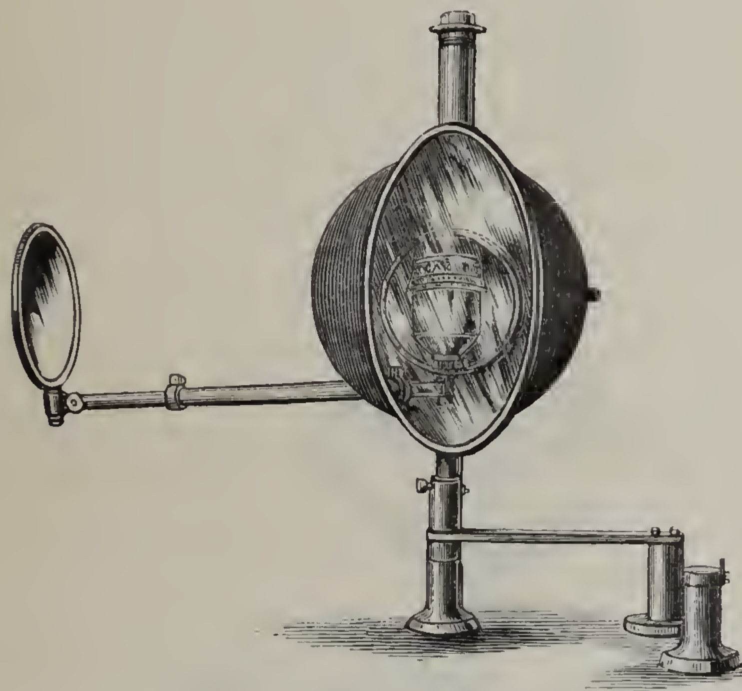

Fig. 16.

zero point from which measurements should be made, whereas, strictly speaking, the principal focus formed by the reflector should be taken as the zero point. Inasmuch, then, as this focus may be several inches away from the flame, and as the length of the bar usually employed is 60 inches, it is evident that serious errors may be introduced

by the difference between the real and the assumed zero point.

To establish the existence of such an error, and to eliminate

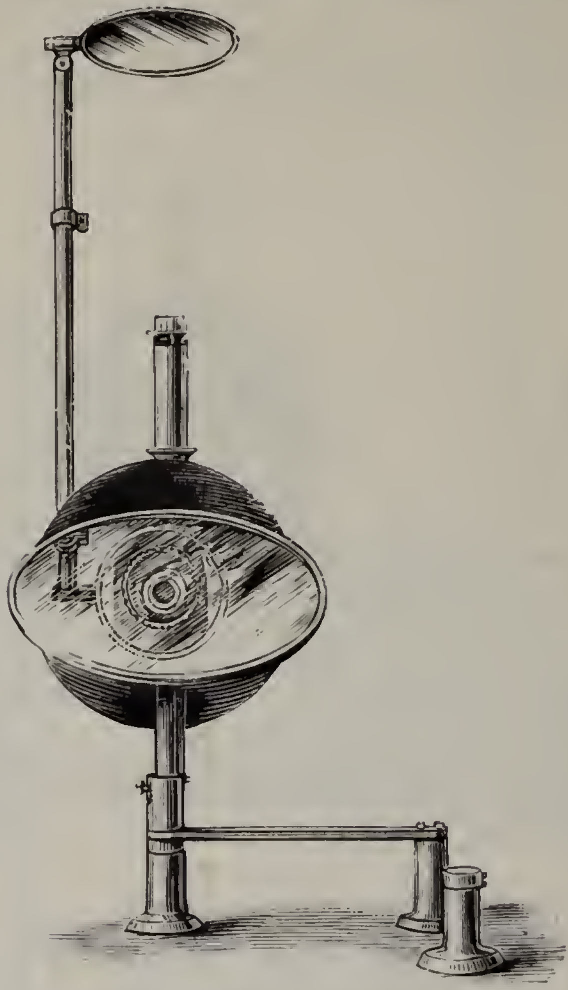

Fig. 17.

it, two things are necessary—viz., that readings should be taken with bars of various lengths; and that the length of the bar should be very great compared with that between

the real source of light and the focus formed by the reflector. Both these points are secured by the use of the Holophotometer. The instrument is mounted upon a table capable of being moved nearer to, or further from, a fixed table containing a graduated bar with moveable disc (say, of the Letheby pattern), and having a standard lamp fixed at the zero of the bar. The lamp to be measured is mounted upon, or is in rigid connection with, the moveable table; and it is therefore not moved during a series of readings.

The Holophotometer consists of an axis working friction-tight in a collar supported by a vertical pillar. The axis is accurately fixed at the same height as, and in a line with, the centre of the disc. At the end nearest to the disc is placed a large mirror, with its centre concentric with the axis, but so arranged that the plane of the mirror may be inclined and clamped at any angle to the axis. At the other end of the axis is fixed a telescopic arm, carrying a smaller mirror, which is capable of being turned into any required position. The arm being rigidly fixed to the rotating axis of the instrument, to which is also attached the larger mirror, it follows that the rotary motions of the mirrors about the axis are identical. The angles of rotation are measured by the indications upon a divided circle attached to the moving axis, and are shown by a pointer fixed to the upright support.

The mirrors are adjusted in such a way that the light from the lamp to be measured falls upon the smaller mirror; thence is reflected on to the larger one; and finally along the axial line of the Photometer disc. As both mirrors rotate together, it follows that if a horizontal beam is reflected correctly, all other beams will find their way along the axis of the Photometer. If, therefore, the arm carrying

the small mirror be moved through various angles, it will receive the light emitted from the lamp at those angles, and the light will at every angle be transmitted along the axis of the Photometer. The divided circle is made large enough to serve as a complete screen of all direct light; and only the light falling on the small mirror can find its way to the disc. In order that absolute, as well as comparative, tests may be carried out, only one additional measurement need be made. The direct horizontal light is measured without the interposition of the Holophotometer (which is mounted so as to be easily moved out of the direct line); then the mirrors are interposed, and a new measurement is made. The additional path travelled by the light is allowed for in calculation; and thus the absorption of the mirrors is determined once for all for the particular character of light under measurement. It is only necessary afterwards to multiply subsequent values by this coefficient of absorption, in order to obtain absolute measurements at various angles. The absorption of the two mirrors employed is stated to be only 1·8 per cent.

The employment of mirrors in Photometry has sometimes led to serious errors; but it will be seen by the foregoing description that, inasmuch as the relative angle of the mirrors is never changed, and as their absorption is easily calculated and allowed for, the only objections to their use have been guarded against and avoided.

In order to eliminate the second source of error mentioned above—viz., that arising from the formation of a principal focus—it is only necessary to take a series of readings with the table in one position, and then move it to a greater distance and take another series. If a focus is

formed at a sufficient distance to produce an appreciable error, it will clearly appear in the difference between the readings at the two distances; and then it is only necessary to wheel the table to such a distance that the discrepancy is inappreciable. In other words, this is equivalent to using a bar of sufficient length to make it practically infinite compared with the distance between the focus and the real source of light.

The instrument has been designed specially for use in lighthouse work, where it becomes of the highest importance to measure accurately the total light given by any lamp, and not only that emitted in any one particular direction, which may or may not be the maximum.

## CHAPTER IV.

## THE "JET" PHOTOMETER AND ILLUMINATING POWER METER.

ALTHOUGH not strictly "Photometers," these instruments are so frequently met with for the purpose of the gas-maker in affording him a ready means of ascertaining the value of the gas in the course of its progress through the various operations, that it would not be proper to omit a description of them here.

*Lowe's Jet Photometer, improved by Sugg.*—This instrument is a delicate pressure-gauge with a jet burner on the top, from which a gas-flame 7 inches in height is burnt. The indicator is a pointer actuated by a float in the body of the instrument, which float is elevated by the pressure of the gas admitted through the inlet-pipe from the main. The pointer indicates upon the dial pressures in hundredths of an inch up to $1\frac{1}{2}$ inches. With the exception of the "Jet," the contrivance is simply a King's Gauge, having a delicate regulating cock, and a water-line regulator.

The following directions are given for its adjustment and use:—In fixing the instrument, care must be taken to have it placed perfectly level upon a firm base, so as not to be affected by vibration or other disturbing causes. Fill

the tank with water up to the overflow-line. Hang on the float so that it falls on the left side of the wheel. Let the balance-weight cord have one turn round the wheel; and it will then hang close up to the wheel on the right side. Hold the wheel with the thumb and finger of one hand, and shift the pointer (which is loose on the shaft) with the

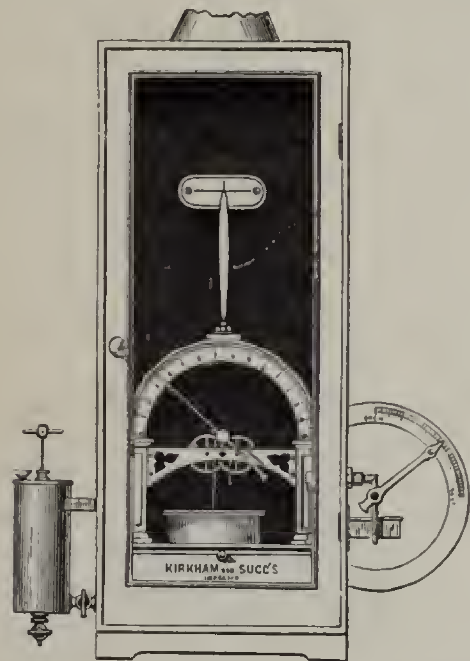

FIG. 18.—LOWE'S JET PHOTOMETER.

other, till it stands at zero, taking care that it works freely. It is necessary once a day to turn off the inlet-cock and open the vent-cock, in order to ascertain whether the pointer will fall to zero when the pressure is off. If it does not do so, the water-line must be readjusted as follows:—

Turn on the cock between the well of the pressure-gauge and the brass cylinder fixed on the left-hand side of the

instrument, which latter is the water-line regulator. When this cock is open, the water in the cylinder rises to the height of that in the well. A plunger, which nearly fits the cylinder, is attached to the cover of the latter by means of a fine-screwed piston-rod terminating in a milled head. If it is made to descend into the water, it causes a displacement equal to the bulk of that portion which is forced below the water-line; and the water displaced goes into the well of the pressure-gauge, moving the pointer in the direction above zero. If, on the other hand, the plunger is raised out of the water in the cylinder, the bulk withdrawn is immediately replaced by water from the well of the pressure-gauge, and the pointer is moved in the direction of zero.

Note.—The alteration of the water-line is caused by evaporation, but the position of the pointer is sometimes altered by the effect of the atmosphere on the float-line.

The pointer having been properly adjusted, the communication between the well and the water-line regulator is closed, and must not be reopened until it is required to make another adjustment of the pointer.

Connect the apparatus with the gas, and adjust the double governor by turning on the regulating cock, lighting the jet, and weighing down the gasholder nearest it to give 9-10ths or 10-10ths of an inch pressure. Then regulate the flame to the 7-inch mark. The pressure required to give a 7-inch flame is an index to the illuminating power—thus, 16-candle gas will give the standard 7-inch flame at 0·63 inch pressure at the point of ignition, as shown on the dial. Gas of 14-candle power requires 0·68 of an inch to give the standard flame.

*Sugg's Illuminating Power Meter.*—In February, 1876, Mr. Sugg read a paper before the Institution of Civil Engineers on "Estimating the Illuminating Power of Coal Gas," from which the following description of the Illuminating Power Meter is extracted:—

This instrument has been designed by the inventor

principally for the purpose of aiding engineers in the examination of coal and other substances suitable for gas-making. It is intended to test the illuminating quality of all gases under similar circumstances, and to show their relative commercial value.

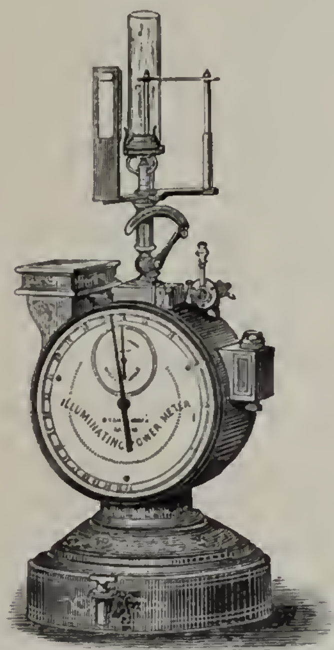


FIG. 19.—SUGG'S ILLUMINATING POWER METER.

A "London" Argand burner, provided with a cylindrical chimney, is fixed on the top of a pillar screwed on to a hollow rectangular base, which is firmly soldered to the outer case of an experimental meter. This base has no communication with the inside of the meter-case. That part of the pillar between the top of the base and the burner forms a cock, the gas-way of which is not drilled in the usual manner, but is slotted across the plug. The sides

of this gas-way being parallel to each other, the cock opens when the lever is turned by regular gradations until it is full open. A quadrant, divided into 45 equal divisions, attached to the cock, enables the operator to regulate the flow of gas to any required rate, with precision. Above the quadrant a sighting frame is fixed, having two upright pillars, crossed by a flat bar at one end, and at the opposite end a frame fitted with blue glass. A scratch is made across the glass exactly 3 inches above the solid part of the frame. The bottom of the opening, the top of the burner, and the termination of the thick part of the back columns, are all on the same level. The scratch on the glass, and the bar which crosses the back pillars, are also on the same level, and parallel to the three lower points just mentioned. By these arrangements, the operator is enabled to adjust the height of the flame to the level of the scratch and the back bar.

On the left side of the hollow base on which the pillar stands is a tube which connects this base to the outlet of a double governor which serves to maintain uniformity of pressure during the time the instrument is in use.

On the right of the hollow base is fixed a two-way cock, with a lever ending in a knob fixed to its plug. The cock is quarter stopped; so that when it is turned in one direction as far as the stop, it is full open, and in communication with the inside of the meter, which is full of measured gas. In this position the measured gas passes through the length of the plug of the cock, and by means of a tube fixed to the end of the cock at one end, and to the inlet of the double governor at the other, it finds its way through the governor to the hollow base, and finally to the burner. While the

gas is passing to the burner by this route, the measuring-drum of the meter revolves; but if the lever of the cock is turned in the opposite direction until it meets the stop, another route is opened for the passage of the gas. Now it proceeds directly from the inlet of the meter without passing into the measuring-drum, through the length of the plug of the cock, and out by the same tube as before to the inlet of the governor, thence to find its way to the hollow base and the burner. In this position of the lever the measuring-drum of the meter is at rest, and the gas is unmeasured. The governor having been properly adjusted, and the meter having from 8-10ths to 10-10ths of pressure at its inlet, this change in the position of the lever will not influence the height of the flame. The index-hand is attached to the arbor of the measuring-drum, and revolves with it; both making a revolution in the same time. The dial is divided into divisions corresponding with the illuminating power, in average parliamentary standard sperm candles, of the different qualities of gas which will give a flame of 3 inches in height. Thus, if the meter is supplied with 16-candle gas, and the flame is maintained at 3 inches, the index-hand will make one complete revolution in one minute. If the meter is supplied with 12-candle gas, and the flame is maintained at the 3-inch line, the hand will make one revolution, and a part of another, arriving at the figure 12 in one minute. With 20-candle gas it will make less than a complete revolution in one minute, and arrive at 20. The instrument is provided with a minute clock, with one pointer hand, which makes a complete circuit of the small dial in one minute. This dial is divided into 60 equal divisions representing seconds.

On the right of the cylinder which forms the outside case of the meter is the water-line gauge, fitted with back and front glasses. At the correct water-line, these glasses are scratched across. On the top of the water-gauge is a large nut, which can be unscrewed when it is required to fill the meter or clean the gauge glasses. The plug at the lower part of the gauge is for the purpose of running out the water when there is too much in the meter.

The mode of making a test is very simple. Turn the lever so as to make the gas pass through the measuring-drum, and let it get rid of all air or other kind of gas in it. Light the burner and adjust the flame to 3 inches in height. Then, when the large hand arrives at 16, change the position of the lever, so as to make the gas pass to the burner without going through the measuring-drum. The large hand will then stop at 16. Wind up the clock by means of the *remontoir* on the top of the meter just in rear of the dial ring. Start the clock by moving the slide, which is on the left of the meter, close to the governor. Then, when the hand of the clock is passing any one of the divisions of the minute, change the position of the lever of the bye-pass, so as to make the gas pass through the meter. When the minute hand has made one complete revolution, stop the meter by means of the lever, in the manner before described, and read off the illuminating power. The minute clock should not be stopped either before or after the observation, unless it is desired to put the clock entirely at rest.

## CHAPTER V.

## DISCS AND DISC-HOLDERS.

THE most essential feature of a Photometer is the "disc," which is the real indicator of the intensity of the opposed lights. The two forms in use in this country are those known as the "Bunsen," so called after the inventor, and the Leeson or "Star" disc. The former, or greased disc, under ordinary circumstances, with lights of equal colour, is all that can be desired; but, when used for testing the electric light, or gas-burners of the recuperative class, it is very unsatisfactory, and at times useless, in consequence of the great difference in tint between the light emitted from the standard and that from the burner under examination. The Author has, therefore, abandoned its use for these purposes; and employs a modified form of the Leeson or "Star" disc. As originally designed, this disc was unsatisfactory in consequence of the "cockling" of the two thin papers on either side of the perforated stout paper. To such an extent was this fault found to interfere with the readings, that the Gas Referees some time back disallowed its use at the Metropolitan Gas-Testing Stations under their charge. Finding that the "Bunsen" disc did not answer all the purposes required, the Author modified the "Star" disc by

pressing together the three papers of which it is formed, with very thin starch water, and drying the moist disc under pressure. This treatment effectually prevented "cockling;" and the use of the disc in its present form is sanctioned by the Gas Referees. The great advantage of this disc is that very sharp readings are readily obtained with totally different coloured lights—red and blue lights being compared with the greatest ease.

The student is very apt to accept a new disc of either pattern as affording correct readings. This is an error that cannot be too carefully guarded against. It was known when the disc was first introduced; and Alfred King provided for reversing the disc in his original Photometer, constructed more than forty years back. Unfortunately, till the last few years the method of mounting the disc made the task of reversing it such a clumsy operation that few operators conscientiously performed it at least once in a series of ten readings—the practice being more honoured in the breach than in the observance, with the result that occasionally after a time a disc became discoloured on one side, and then gave false results.

In 1878, Mr. R. M'Minn proposed to mount the disc in a frame which freely rotated upon centres above and below the middle, with stops to arrest it in the proper position for taking observations. When the Author designed the "Radial" Photometer already described, the disc was mounted on a fixed frame as usual, but which turned *with the mirrors* on a pivot at the back. The movement of the reflectors as well as of the disc was evidently such an advantage, by tending to equalize any difference in their setting or brilliancy, that the Gas Referees sanctioned the system

for use in the official Photometers. The convenience experienced in checking the action of the disc has resulted in the continual practice of one-half of the readings being taken with the disc in one position, and the remainder with both it and the mirrors reversed; thus affording an assurance of accuracy, practically unobtained before, because of the difficulty of effecting a reversal, which was even greater in the case of the "Letheby" sighting-box on an open bar than in the "Evans" pattern.

The "Bunsen" disc used in this country, as made by Messrs. Sugg and Co., is a circular piece of stoutish paper coated on the circumference on either side, with great care, with sperm in a melted state. The centre is thus left untouched. In Germany, Herr Elster makes the disc of thinner paper, having three rectangular grease patches in the centre. Both forms give very delicate indications. Several alternative proposals have been made; amongst them being the suggestion of Joly to use two rectangular blocks of spermaceti, either with or without a piece of tinfoil pressed between them. Herr Elster has made a modification of this, by replacing the soft spermaceti with opal glass. The Author's trials of these, however, have not induced him to prefer them to the simple paper disc.

When first setting up a disc for use, several experimental readings should be taken; and if any material difference is found between the indications when one side or the other is turned towards the standard flame, it should unhesitatingly be rejected, as no amount of after allowance can compensate for the trouble and doubt arising from contradictory results. The disc should be clean, and perfectly free from scratches or other markings of any kind; it is but

sorry economy to work with a defective instrument. The Gas Referees went so far, a short time back, as to order a new disc to be used every week. As, however, a good disc, when taken care of, will last much longer than that period, the point has not been insisted upon; but that is no excuse for the continued use of a defective one, which should be ruthlessly destroyed as soon as detected.

## CHAPTER VI.

## STANDARDS OF LIGHT.

IN England the standard of light is a sperm candle. In the Metropolis Gas Act, 1860, it is described as "sperm candles of six to the pound, each burning 120 grains per hour." In France the standard is the "Carcel" Lamp, burning refined colza oil at the rate of 42 grammes per hour. In Germany the present standard is a paraffin candle of which ten weigh 500 grammes, and the flame should have a height of 50 millimetres. While these are the three recognized legal standards, many proposals have been made for substitutes for them. It will be well, however, to deal with the present legal instruments first, and then to describe the various systems suggested as improvements upon them.

*The Sperm Candle.*—The only definition of this legal candle is that given above, with the addition of the Gas Referees' instruction that, when the sperm actually consumed falls short of 114 grains per hour, or rises above 126 grains per hour, the test is to be rejected. In practice these figures are determined by noting the time required by two candles to consume 40 grains weight of sperm, which should fall within the limits of nine-and-a-half minutes,

and ten-and-a-half minutes, or, calculated on the weight consumed in ten minutes, 38 and 42 grains. The prescribed rate of 120 grains per hour would be 40 grains for two candles in ten minutes. The weight of a single candle as supplied by the maker should be 1167 grains nearly. The extreme variations from this weight rarely exceed 20 grains, and more generally fall within a few grains. The length of the candle varies with different makers (in fact there are only two: Messrs. Miller and Co., and Messrs. Brecknell, Turner, and Co.) from 8¼ inches to 9 inches, measured from the "shoulder." The diameter at the shoulder is very nearly 8-10ths of an inch, and 8½-10ths to 9-10ths at the bottom. The Author is indebted to Messrs. Miller and Co. for the following definition of what they understand to be a "sperm candle" according to the Act of 1860 :—

"We think that there can be no doubt that at the time the Act was passed, a sperm candle was understood to consist exclusively of spermaceti (the product of the spermaceti whale), pure white, and dry, having a melting-point of as nearly as possible 109°, and to which was added just so much air-bleached bee's-wax, having a melting-point of 140° as would suffice to break the crystals of the spermaceti ; the rate of combustion fixed at 120 grains an hour being secured by a properly-proportioned cotton plait serving as the wick. With regard to the size of the candles to be used, we have never attempted to make candles which should individually weigh $\frac{1}{6}$ lb., as we have understood the intention of the Act to be to indicate that the candles to be used should be those known in the trade as 'short sixes,' and which do approximately weigh six to the pound."

Unfortunately, considerable variations have taken place in the number of threads to each strand in the wick. This has arisen from the endeavour of the makers to free the spermaceti as much as possible from the "sperm oil," and thus obtain a more solid product. Naturally a higher melting-point has thus been obtained, which necessitates the employment of larger wicks to effect the same rate of combustion—a remedy which, unfortunately, reduces the light yielded per unit of sperm consumed. In the words of the Report of the Standards of Light Committee of the British Association for the Advancement of Science, presented in 1888: "Thus the effect of the improvements in spermaceti has been that standard candles give less light than they gave ten years ago, and probably still less than they gave at earlier dates, when the average consumption of candles of six to the pound was 140 grains per hour."

This conclusion, so authoritatively given (for that Committee was composed of the most eminent independent men of the day), is in strict conformity with the experience of a large number of most able photometrists. On the other hand there is on record a statement to the contrary effect, made by two gentlemen of no little skill—viz., Messrs. Heisch and Hartley, who in 1883 said: "We may here mention what we are convinced to be a fact—namely, that sperm candles, generally, now develop more light per grain of sperm burned than they did several years ago." This statement is so entirely contrary to the experience of the Author that he cannot accept it as a fact in preference to the British Association Committee's deliberately-expressed and fairly-argued conclusion.

Whatever may be the opinion of one party or another,

candles are still the legal standard; and our business for the present is to consider the proper method of using them. The procedure is as follows:—The candle selected for the test should be a straight one, with the wicks central in the longitudinal axis; and it should not be too tapered from end to end. The sloping top is to be cut off at the shoulder; and the candle then equally divided in the centre. The two new ends thus obtained are to be trimmed so as to form new wicks, which, when lighted and bending, are to be turned so that the plane of the curvature of one wick shall be perpendicular to the plane of the curvature of the other wick. The candles should be left mounted on the Photometer-balance for at least ten minutes, or longer if necessary, until the "cups" are "fairly dry," and the wicks properly bent, while at the same time the ends glow with a clean red heat. If the candles are used while the wick is in a vertical position, it is certain that the results of the tests of the opposed lights will be too high.

In Schedule A, Part 2, of the Gas-Works Clauses Act, 1871, it is stated that "the candles are to be lighted at least ten minutes before beginning each testing, so as to arrive at their normal rate of burning, which is shown when the wick is slightly bent and the tip glowing." Although it does not appear that this Act has been overruled by any subsequent one, the Instructions of the Gas Referees omit the latter part, and simply say that the candles shall attain "their normal rate of burning." Probably they presume that this expression relates as much to their *condition* of burning, as to the actual rate at which the sperm is volatilized; otherwise it would be correct to use a candle

with the wick so disposed that a large proportion of the sperm escaped as unconsumed carbon.

The candles, having thus been brought into readiness for the test, are to be counterpoised upon the balance until their weight is just in excess of that of the counterpoise by a grain or two. The experimental seconds clock (fig. 18) being in readiness, with the hand pointing at zero, the candle-balance is to be watched; and, as soon as the pointer passes the zero mark, the clock is to be started. A 40-grain weight is then to be carefully put into the pan under the candles. which will bring them again to rest, and

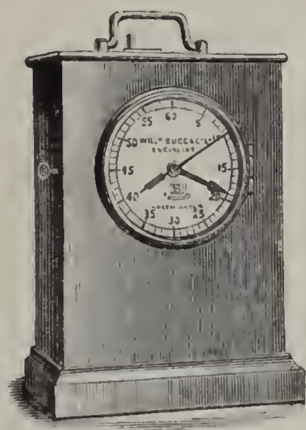

FIG. 18.

the readings of the Photometer-disc proceeded with, one for each minute—the first one to be taken immediately, so that ten will have been made soon after the end of the ninth minute. The candle-balance is then once again to be watched; and, as soon as the pointer passes the zero mark, the clock is to be stopped, and the time noted. The calculations involved in making the necessary corrections are simple. Let it be supposed that the time required for the

candles to consume 40 grains of sperm is 10 minutes 30 seconds; the calculation will be :—

10 min. 30 sec. = 630 seconds : 40 : : 600 : $x$ = 38.1 ;
or, shortly, divide 24,000 by the time, in seconds, taken to consume the given weight of 40 grains. For convenience a table is usually kept handy for reference. A copy of this will be found in the "Appendix."

A very short experience with candles will suffice to convince a careful operator that the only way to attain concordant results is to burn them in such a manner that they are not over-heated by exposure to an excessive temperature in an insufficiently ventilated chamber, such as that of the original "Evans" Photometer. They give the best result in a perfectly open room free from draughts. Although this cannot always be obtained, good results may be ensured by surrounding them with a large box (say) 18 or 20 inches square, perfectly open for 3 or 4 inches at the bottom, and closed at the top by a circular aperture at least 6 inches in diameter. This arrangement provides for a steady current of cool air free from side and top draughts, in which the combustion of the sperm will be uniform and complete, if only the candles are made with proper wicks. Bad wicks, which burn nearly upright or with a knob of charred thread at the end—technically called "a rose"—will never give good results; and, as such candles cannot be said to burn at their "normal rate," they should be rejected.

While candles are, no doubt, unsatisfactory as a standard, they are not, when properly made and used, so bad as many of the published results have caused them to appear. The fault in great part lies in the loose way in which they are

defined, and in their being burnt in ill-ventilated and consequently over-heated chambers. The fact is, they have been "more sinned against than sinning." The most reliable and concordant results have been obtained by the Author on the "Portable" Photometer. Not one of the many patterns of various "improved" instruments has surpassed, nor, it may truly be said, equalled, the even indications which this form of instrument has enabled candles to afford. It is systematically used in ordinary rooms; requiring only reasonable care to avoid draught from open doors or windows. As an acknowledged authority has said: "All the 'coddling,' so to speak, which the instruments had received during the last 20 or 25 years, was really detrimental to the original simplicity and beauty of the instrument." In the "Portable" Photometer, as used by the Author, this "coddling" has been cut away; and the only retained improvements on the original form of King's Photometer are the sighting-box of Letheby and the Author's rotating disc and mirror holder, with the addition of certain necessary velvet curtains, to protect the direct rays from the lights impinging upon the eyes of the observer, and to prevent reflected rays from surrounding objects interfering with the readings of the disc.

"*Carcel*" *Lamp.*—This lamp, named after the inventor, was devised in 1800. The wick is annular, as first arranged by Argand. The oil used is refined colza, which is forced up to the wick by means of a small clockwork pump. M. Monnier, in his "*Étude sur les Étalons Photométriques,*" gives the following instructions for the use of this standard:—"The conditions to be observed when testing with the Carcel Lamp are by no means definite, as each lamp

must first be tested before being used as a photometric standard. The rule, however, is that the height of the wick and chimney must be so arranged that the consumption of oil must be within the limits of 38 and 46 grammes per hour; but for exact experiments it is preferable to restrict these limits, and maintain the consumption between 40 and 44 grammes per hour. The light given by the lamp is corrected by simple calculation on the assumption that 42 grammes of oil per hour equals one 'Carcel.'"

The results of experiments made by MM. Audouin and Bérard show, firstly, that an increase in the height of the wick up to a certain point—10 millimetres—augments the consumption of the oil as well as the intensity of the light; and that beyond that point both consumption of the oil and intensity diminish. Secondly, that the elevation of the constructed portion of the glass chimney tends to augment the consumption of the oil in increasing ratio; but that there is a point where, although the consumption continues to increase, the intensity diminishes. Consequently, there is a height of the glass which corresponds to the maximum illuminating power of the lamp.

For each experiment a new wick is necessary, which must be cut level with the wick-holder. The lamp, replenished with oil up to the level of the gallery, must be allowed to burn for half-an-hour before commencing the experiment. The height of the wick must be from 8 to 10 millimetres, and the shoulder of the glass about 7 millimetres, above the wick, and that of the flame about 36 millimetres. The calculations for correction from the observed weight of oil consumed are facilitated by reference to the table given in the "Appendix."

The value of the "Carcel" in terms of English sperm candles was determined by Mr. Sugg in 1870 as 9·6 candles. A series of experiments conducted by the Author in 1885 gave 9·4 as its mean value. It may, therefore, safely be inferred that it is equal to about 9·5 English candles.

*The German Paraffin Candle.*—The Author is indebted to Dr. Hugo Krüss, of Hamburg, for the following description of the German Association paraffin candle, according to the resolution of the German Association of the Gas and Water Profession in the year 1872, at their Twelfth Annual Meeting in Würzburg, and the application of the candle for photometric purposes :—

"The paraffin candles made for the Association under the supervision of a Special Committee are issued by the Manager at cost price. Ten candles weigh 500 grammes. Each candle has a true cylindrical form and a diameter of 20 millimetres, and is made of the purest possible paraffin, with an addition of 2 per cent. of stearine. The point of solidification is 55° C. The wick is plaited of 24 cotton threads as uniformly as possible. One metre of wick in a dry condition weighs 0·668 gramme. A red thread in the wick distinguishes the Association candle from others.

"The flame of the candle in light trials should have a height of 50 millimetres, measured from the commencement of the flame at the wick to the point. To obtain this height, leave the lighted candle to burn quietly until an even tray of liquid paraffin is formed. By carefully snuffing the wick, if necessary, the flame is to be brought to the height of 50 millimetres and maintained at that height. In this condition the consumption of paraffin amounts to 7·7 grammes per hour.

"The most suitable temperature of the rooms in which photometric measurements are made is taken at 14° Reaumur (17·5° Centigrade)."

The contra-distinction between the elaborate care thus exercised and the comparatively haphazard English system, is most marked. The precautions unfortunately appear to be in vain, as the Germans are actively in search of a more definite substitute. At present they are somewhat in favour of the amyl-acetate lamp; but, like their English *confrères*, they are not satisfied with its red colour.

## CHAPTER VII.

## PROPOSED SUBSTITUTES FOR CANDLES.

THESE are, in the order of their introduction: Keates's Lamp; Harcourt's Pentane; Methven's Screen; Sugg's 10-candle Screened Argand; Violle's Molten Platinum; Hefner-Alteneck's Amyl-Acetate Lamp; Dibdin's Pentane Argand; Sugg's 16-candle Argand; Harcourt's Original Pentane Lamp, and Screened Pentane Lamp. Various other suggestions have been made; but apparently only to fall through.

*Keates's Lamp*, when first introduced in 1869, was arranged to yield a light equal to 10 candles. Subsequently it was improved, and made to yield a light equal to 16 candles. The essential differences between this lamp and the Carcel are: (1) Oil consumed: sperm instead of colza. (2) The size of the flame of the Carcel is regulated by two things—first, the height of the wick; and, secondly, the height of the shoulder of the glass. With the Keates lamp, the height of the flame is regulated solely by the wick; the position of the glass being constant. (3) The Carcel does not provide for such an even and well-regulated supply of air to the flame as is the case with the Keates lamp. The wick of the Carcel stands unprotected save by the chimney; whilst that of the Keates is surrounded

with a metallic cone to direct the air-currents upon the flame—the effect being that this is absolutely steady, but that of the Carcel is continually oscillating, the flame being momentarily higher at one portion than another. (4) The illuminating power of the Carcel is 9·5 candles, while that of the Keates is 16 candles.

The lamp is a modified form of the "Moderator." When burning sperm oil at the rate of 925 grains per hour, with a 2-inch flame, the light is equal to 16 candles. As with the candles and the Carcel, the consumption of oil must be weighed and correction made (for table, see "Appendix"). Sugg has modified the lamp by placing a screen having an aperture in front of the flame. This aperture may be regulated to pass light equal to 2 or 10 candles, in which case no weighings of the oil consumed are required.

At one time the Author strongly advocated the use of this lamp as a standard in place of candles—as in his hands it gave results of a remarkably uniform character. Further research, in which a number of experienced operators took part, demonstrated that the practical difficulty experienced in obtaining a flame of uniform character was greater than had previously been found to be the case; and to such an extent was this experienced that, in face of the more easily managed Pentane Air-Gas and Pentane Argand standards, it had to be put on one side.

*Harcourt's Pentane Air-Gas.*—Mr. Harcourt introduced this form of proposed standard to the notice of the Physical and Chemical Sections of the British Association at their meeting held at Plymouth, in August, 1877, when he gave the following description of the "pentane":—

"For the standard combustible, I employ a mixture of

air with that portion of American petroleum which, after repeated rectification, distils at a temperature not exceeding 50° C. This liquid consists almost entirely of pentane, the fifth member of the series of paraffins. I have made three or four analyses of the liquid, which, though they scarcely distinguish between pentane and the adjoining hydrocarbons of the same series—the proportion of carbon to hydrogen being in pentane, carbon 83·3, hydrogen 16·7; and in hexane, carbon 83·7, hydrogen 16·3—would reveal the presence of small quantities of hydrocarbons richer in carbon. I have also determined the vapour density of the liquid. The density of gaseous pentane compared with hydrogen is 36; that of hexane 43. I find the vapour density of the liquid, distilled twice below 50° C., to be 37. The lighter portions of purified American petroleums have been carefully examined by Ronalds, Cahours, Warren, Schorlemmer, and other chemists, and have been found to consist of the following hydrocarbons:—Tetrane, boiling between 4° and 0°, and having a specific gravity of 0·6 at 0° C.; two isomeric pentanes, one boiling at 30°, and the other at 37°, and having at 17° a specific gravity of 0·626 (Schorlemmer), 0·628 (Cahours), the proportion of which appears to vary, since the hydrocarbon separated by Cahours boiled at 30°, while Schorlemmer states that the pentane in the samples examined by him consisted almost wholly of the variety boiling between 37° and 39°; hexane, which boils at 68° C., and has a specific gravity, at 16° C., of 0·669. The liquid I use has a specific gravity which has only varied in different samples between 0·6298 and 0·63, except in one case, in which, probably owing to the temperature of distillation having

been allowed to rise too high, it was 0·631. It would not be difficult, by rectifying at 40°, to obtain almost absolutely pure pentane. But I do not think it necessary to limit the distillation to this temperature, because the yield at 50° is rather larger; and it seems hardly possible that the admixture of a small and nearly constant proportion of a substance so little different as hexane, can affect the quality of the liquid as a combustible. Also I find, having distilled ten or twelve samples of the liquid, using about three litres each time, that I get a constant specific gravity."

The method of preparing the air-gas from the liquid pentane is very simple. For every cubic foot of gas, 3 cubic inches of the liquid pentane are required—the air being measured at a pressure of 30 inches of mercury and a temperature of 0° C., the pentane being measured at 60° Fahr. In practice, 3 cubic feet of air and 9 cubic inches of pentane are usually taken. Mr. Harcourt's method of introducing the liquid pentane into the gasholder containing the measured volume of air is to pass the bent end of a pipette to the bottom of a syphon-tube sealed with water. The long limb of this syphon passes through a cork fitted tightly in the top of the bell of the holder. On opening the stop-cock of the pipette, the pentane passes down through the tube, and, taking the direction of the bent end, rises upward through the column of water and over the top bend of the syphon into the bell. Finding this system very liable to accidents, the Author uses another of a more simple and reliable character. The bent end of the pipette is cut off, and the pipette ground accurately into a second shorter and stouter tube provided with a stop-cock.

This short tube is fitted into the crown of the bell of the holder by means of a tightly-fitting india-rubber cork. The charging of the holder with pentane, without either letting air into the holder or losing pentane, thus becomes a matter of absolute certainty. The pentane pipette is first filled in the usual manner, and then the ground end firmly but gently fitted into the open end of the tube in the bell of the holder, and the two stop-cocks opened—viz., the one in the short tube and the one on the pipette—when the pentane will run through the tube into the holder without hesitation or possibility of loss. When the pipette is nearly empty, it is closed at the top with the forefinger, and the bulb warmed by clasping it with the hand, when the pentane vapour, becoming expanded, drives the last portions of pentane into the holder. The stop-cock in the short fixed tube, which is ground perfectly gas-tight, is closed, and the pipette removed. With this system the Author has never had a failure in the preparation of the air-gas. After the admission of the pentane into the holder, the admixture must be allowed to stand for at least four hours—and preferably overnight.

The burner used with the standard gas has an opening $\frac{1}{4}$ inch in diameter. The length of the brass tube, which the gas enters near its base, is 4 inches; its diameter is 1 inch; and the thickness of the disc which forms the mouthpiece is $\frac{1}{2}$ inch. The height of the flame is accurately adjusted to $2\frac{1}{2}$ inches. The specific gravity of the liquid, the volume of the gas yielded, and the rate of burning to produce a $2\frac{1}{2}$-inch flame, were defined by Mr. Vernon Harcourt in the following letter to the Board of Trade Committee on Photometric Standards in 1881.

"To the Committee on Photometric Standards.

"Aug. 5, 1881.

"Gentlemen,—I send, at your request, a further account of the method of preparing the gas whose combustion furnishes the standard of light I have proposed.

"The liquid used for its preparation is the lightest and most volatile portion of American petroleum, obtained by purifying and rectifying in the manner already described the 'gasoline' or light petroleum procured by the air-gas companies in this country from Pratt, of New York. The rectified liquid begins to distil at about 65° Fahr.; and the distillation is almost complete when the temperature of the vapour has reached 120°. The liquid consists of hydrocarbons of the paraffin series, chiefly of pentane, but with an admixture of the homologous substances tetrane and hexane. Its specific gravity varies between the limits 0·628 and 0·631 at 59° Fahr.; but recent experiments have shown that an air-gas of the same illuminating power is obtained with samples varying in specific gravity between 0·614 and 0·645. The vapour of the liquid weighs two-and-a-half times as much as an equal volume of air.

"By allowing a measured volume of this liquid to diffuse into and mix with a measured volume of air in the proportion of 3 cubic inches of the liquid to every cubic foot of air under an atmospheric pressure of 30 inches of mercury, and at the temperature of 60° Fahr., a standard air-gas may be prepared in any required quantity.

"A gasholder of the size and form of that set up in the office of the Gas Referees is convenient for making and storing a quantity of the standard air-gas sufficient for thirty testings. It consists of a cylindrical bell of about 7 cubic

feet capacity, suspended and counterpoised in the usual manner over a tank having an annular space filled with water. A graduated scale attached to the bell serves to measure the volume of air drawn in, and also the volume of vapour formed from the measure of petroleum which is poured through a tap into the holder. When 3 cubic feet of air and 9 cubic inches of light petroleum are used, the total volume of standard air-gas formed is 4·05 cubic feet. The observation of this volume furnishes a check on the preparation of the standard air-gas. Allowing a margin of 1 per cent. each way for small errors in making and measuring the gas, and for variations in the vapour density of the rectified petroleum, I would propose, in defining the standard air-gas, to require that the volume produced from 3 cubic feet of air and 9 cubic inches of petroleum (specific gravity 0·628-0·631) shall not be less than 4·01 nor more than 4·09 cubic feet. The gas thus prepared is subjected each time that it is used to a further control by the requirement that its rate of burning from a ¼-inch orifice to produce a 2½-inch flame must not be less than 0·48 nor more than 0·52 cubic foot per hour.

"For the name of the liquid used to make the gas, I think it better to drop the unfamiliar word 'pentane,' and to call it 'standard petroleum'—a name which suggests the fact that the liquid is obtained from petroleum by a special process of purification and rectification. The term 'air-gas' appears to have established itself as the name of a combustible gaseous mixture made by saturating air with the vapour of hydrocarbons; and therefore I propose to call the mixed gas, prepared as has been described, 'standard air-gas.'

"I enclose a statement of the results of a comparison made recently of standard air-gas with samples prepared from petroleum distilled at various temperatures ranging between 65° and 120° Fahr. The figures show how small an error would be caused by even considerable variations from the prescribed method of preparing standard petroleum provided a sufficient purification and rectification have been made.

"I am, Gentlemen,

"Yours faithfully,

"A. Vernon Harcourt."

The adoption of the pentane air-gas as a standard in place of candles was recommended by a Committee of the Board of Trade in 1881; by the Metropolitan Board of Works in 1887; and by the Standards of Light Committee of the British Association in 1888. No other proposal has so triumphantly undergone such a severe examination; and it is difficult to understand the objections to its immediate adoption as the legal unit. The Author's experience of this proposed standard is summed up in a few words—viz., The method of preparing the gas is at once easy and safe. The measurement of the volume of gas used is simple and reliable. The adjustment of the height of the flame is a matter of certainty. Its steadiness is all that can be desired, when due care is taken and proper apparatus employed. The colour of the light afforded is precisely the same as that of the ordinary gas-flame. And, what is of the utmost importance, it accurately represents one average English sperm candle.

*Methven's Screen.*—Mr. Methven introduced this method

of obtaining a light of constant illuminating power in 1878, when he read a paper on the subject before the British Association of Gas Managers. The apparatus is exceedingly simple, consisting "of an upright rectangular metallic plate or screen, having a horizontal flange or bracket, upon which a standard 'London' Argand burner is fixed; the latter being supplied with gas through a plug or nose-piece projecting downwards. The upright plate has a slot or hole above the flange or bracket; and this hole is covered by a thin silver plate, having a vertical slot of such dimensions as to allow of the passage of as much light as equals that afforded by two average standard sperm candles when the Argand burner is delivering sufficient gas to give a flame 3 inches in height." Finding that this arrangement was to be depended upon when gas of only ordinary quality was used, Mr. Methven experimented with "carburetted" gas—*i.e.*, gas enriched with hydrocarbons. For this purpose, he adopted the same light petroleum spirit as Mr. Harcourt uses—viz., pentane. He found, firstly, that all the carburetted gases were too rich to be burnt properly from a standard Argand, furnished with a 6-in. by 2-in. chimney, with a greater flame-length than 2½ inches; and, secondly, that with this length of flame, the amount of light yielded was constant and altogether independent of the actual illuminating power of the coal and cannel gases employed. In order to compensate for the greater luminosity of the flame so obtained, he employs an aperture of smaller area than that used with the plain coal gas.

The Board of Trade Committee rejected this proposal in its original form. The idea of carburetting the gas may be looked upon as an outcome of their report, as Mr. Methven

adopted the new method to meet the objections raised agains the plain gas-screen. In 1883, Messrs. Heisch and Hartley reported to The Gas Institute on this proposal in the following terms:—

"It will thus be realized that the range in the qualities of the gases with which the Methven plain-gas standard can be safely used is much wider than has been generally supposed; as in our experiments the extremes are 13·65 and 22·4—a range of 8·75 candles. . . . The Methven standards are simple in construction; not liable to get out of order; and extremely easy to use. They do best, like candles, in an open Photometer; but can be readily used in a closed one, if due care is taken to freely ventilate the Photometer and avoid violent air currents—conditions which are extremely difficult to fulfil with closed Photometers. . . . The only conclusion which can be drawn from such a mass of evidence is that the Methven units are not only perfectly reliable instruments for ordinary gas testings, but are suitable for use in photometric investigations of a much more refined character."

The Author's objection to this proposed standard is two-fold. In the first place, the adjustment of the height of the carburetted flame is a matter of too little certainty, and lends itself to variations of readings in the hands of a biassed or careless operator. Secondly, by selecting a chimney or even *a part of the same chimney*, different results can be obtained, as the glass exposed to the slot acts as a lens; and the character of this lens will affect the results, which are thus left to a great extent to chance. In the presence of a thoroughly reliable standard such as the pentane air-gas—which is safeguarded by various precautions, *and open to*

*subsequent verification*—it does not seem advisable to adopt Mr. Methven's proposal as the legal standard, although, for experimental purposes, it is in many respects an admirable one.

*Sugg's Ten-Candle Standard.*—This standard is obtained by burning gas in a 3-inch Argand flame; the height being accurately fixed by regulating the pressure. The top of the flame is then cut off for photometrical purposes by means of a screen, which still leaves the whole of its width visible, but reduces the height of the light to about 1¾ inches. The standard is mounted on a meter, which registers the amount of gas consumed; and this constitutes an indication of the highest value of the variations of the flame. Thus the standard is not based on the assumed constancy of a portion of a gas-flame, or on the height of flame and pressure of gas; but it is essentially a variable standard, the variability of which is known, and can be allowed for by referring to a table which has been most carefully compiled (see "Appendix").

*Violle's Molten Platinum.*—In this proposal the unit of light is the intensity of that emitted from a square centimetre of platinum in a solidifying condition. In the words of Professor Violle, "the principle of the standard is the constancy of the point of fusion, and the constancy of the temperature during the whole time of the change of state," when the maximum light is given off, and the reading of the Photometer taken. This system was recommended by a Congress of Electricians held in Paris, as an international standard; but in 1881 another Congress rejected it, on account of the difficulty attending its application, and the colour of the light—at the same time recommending the adoption of the Carcel lamp.

The British Association Committee on Standards of Light,

in their report presented in 1888, stated that, in their opinion, Professor Violle's standard of molten platinum is not a practical standard of light, although they were quite prepared to agree to the adoption of the light emitted by a square centimetre of molten platinum as a unit, but not as a standard of light.

The Author tried a modification of this system, which it may be interesting to notice; but unfortunately the results were not sufficiently uniform to recommend its adoption as a standard.

The method adopted was to heat to its melting-point, by means of an oxyhydrogen flame, a piece of platinum-foil placed behind a steatite screen perforated with an aperture smaller than the portion of platinum actually incandescent. This arrangement, while simple in operation, has afforded very promising indications, and seems well worthy of further experimental observation, as there can be little doubt but that an easily-worked and reliable system for obtaining a steady light from molten platinum would find ready acceptance as being definite for all time. When working by this method, the oxyhydrogen flame is gradually increased in intensity until the platinum-foil melts. When this happens, the oxygen is turned off, and a fresh portion of foil which is carried on two rollers—one on each side of the aperture—is brought into position, and a second experiment made; thus, successive readings are obtained if necessary in rapid succession. The foil is wider than the portion actually perforated by the intense heat; so that, by turning a winch-handle, a fresh surface is almost instantly obtained. The operations involved in testing are thus about a quarter of a turn of the winch-handle, and turning the oxygen on and

off at the beginning and end of each test respectively. The aperture in the steatite screen is about one-fifth of an inch in diameter, and it allows light equal to a little more than 2 candles to pass to the Photometer disc.

*Hefner-Alteneck's Amyl-Acetate Lamp.*—The following description (translated) of this lamp is extracted from a paper read by Herr von Hefner-Alteneck before the Electrotechnical Society of Berlin :—

"The unit of light is the illuminating power of a freely-burning flame, which rises above a large wick saturated with amyl-acetate. The wick is contained in a round tube of German silver, which it completely fills, and which is 25 millimetres high, 8 millimetres inside diameter, and 8·2 millimetres outside diameter. The height of the flame is 40 millimetres from the edge of the wick-tube to the point of the flame. The light should not be used for measurement until ith as been burning for at least ten minutes.

"In the form of lamp practically adopted by Herr von Hefner-Alteneck, the proper height for the flame is shown by a gauge-rod fixed into the body of the lamp, and carrying two horizontal sights, with which the point of the flame must be in line.

"The wick is formed of a strand of cotton yarns. The separate threads, to the number of about 15 or 20, are laid together straight, not twisted, until the total size of the wick is such as just to fill up the tube without squeezing. Any slight inaccuracy in this point is not of any great consequence, as the effect will only be to alter the height of the flame, which can then be readjusted by raising the wick.

"It is essential that the wick should be cut quite level at the top ; and this may best be done by turning it up, slightly

separating the threads, and cutting them individually until, on turning them down again into the tube, they all stand at the same height as the top of the tube.

"The quantity of amyl-acetate in the lamp is immaterial, so long as *all* the ends of the wick are immersed. In putting in the wick-tube, care should be taken to press it down firmly on to its seat.

"The illuminating power of the flame is only normal if it is burning in free air—that is, without a chimney. As it is very sensitive to draughts, however, it is desirable, where these cannot be avoided, to protect the flame by a chimney. This should be a straight glass cylinder, 80 millimetres high, and 55 millimetres inside diameter. It is carried in a clip on the rod, which also carries the sights. When the chimney is put on, the flame drops slightly; if it is again brought up to the standard height, the illumination is about 2 per cent. less than when the flame burns free in air. It is, however, preferable to determine the effect of each glass chimney experimentally, by comparing the lamp with and without it against any steady-burning flame. Besides screening the flame from all draughts, it should, as far as possible, be protected from all shaking, which has an immediate effect on the flame, making it jump."

The Author found this flame to be very steady, but considerably less than 1 candle in value when adjusted at the indicated height—viz., 40 millimetres; but when the height of the flame was raised to 51 millimetres, or 2 inches, it gave results agreeing with the Pentane and Methven. The extreme simplicity and portability of the arrangement are strongly in its favour; but, on the other hand, the colour of the light, even when pure amyl-acetate is used, and the flame

fixed at 40 millimetres in height, renders it extremely difficult for various operators to agree ; and, when compared with the pentane, this effect is most marked. This is an important point, as the tendency at the present time is to insist as far as possible upon a white light from all artificial sources ; and the adoption of a dusky flame as a standard of comparison would be a mistake.

Although members of the German Society of Gas and Water Experts have arrived at the conclusion that the steadiness and easy application of the lamp recommends it as a suitable means of comparison for light measurements. they have found that its colour is very unfavourable ; but as they did not know of anything better, they had to put up with it in that respect, in preference to candles, which they find very unsatisfactory, although such elaborate care is taken in their manufacture.

*Dibdin's Pentane Argand.*—This proposal is a modification of Sugg's 10-candle test and Harcourt's pentane. The burner is an Argand of the type used by Sugg, but modified to burn air-gas. The height of the flame is 3 inches, seven-tenths of which is cut off at the top by a screen. The air-gas used is obtained by simply passing air over liquid pentane contained in an ordinary Methven carburetter. By these means a standard flame is obtained independent of the gas supply (which may be used, however, in place of the air, if preferred), and one also free from the defects due to a slight alteration of the height of the flame, as a variation of 1½ inches does not affect the quantity of light emitted beneath the screen cutting off the top of the flame. This proposed practical standard, which is equal to 10 candles (but which can be made of

smaller or larger dimensions if required), has been by some confounded with the Methven; but it is essentially different, and is identical with the arrangement used by the Author in 1879 and 1880 for standardizing the Keates lamp. In it only the *top* of the flame is cut off; and the whole of the light emitted from the lower and blue part of the flame is included in that of the "standard" portion. This admits of the variation of the height of the flame, as, when the flame is lowered, it has less "body" beneath the screen, which reduction is, however, compensated for by less "blue;" and, inversely, when the flame is lengthened, the "body" of white light is increased, and at the same time the amount of "blue" is also increased. A compensating action thus takes place. As it might be thought that temperature would influence the quality of the pentane gas formed by merely driving air over the liquid, the Author tried the experiment of filling the carburetter tank with ice and water, and then changing this for warm water at 90° Fahr. After adjusting the flame to the altered flow of gas thus caused, the indications on the Photometer were precisely the same in either case. A 10-candle standard is by this measure readily and conveniently obtained by the use of the standard combustible proposed by Harcourt; and in this case it is independent of all measurements and corrections beyond the roughest possible approximation to the height of the flame, as pointed out previously. Either carelessness or accident in this respect would not affect the standard as it would in the case of the Methven, which is no longer trustworthy when the height of the flame is varied from the normal.

*Sugg's Sixteen-Candle Air-Gas Argand.*—This proposed

standard is a modification of the above; the essential differences consisting in the altered shape of the flame, and the use of the specially-prepared pentane air-gas, proposed by Mr. Harcourt for his 1-candle standard. This proposal has unfortunately the same defect as the Methven, as slight variations in the height of the flame—although the top is cut off with a screen, as in the Author's pentane Argand—seriously affect the readings on the Photometer, so much so that differences of 1 candle may be readily and unconsciously attained. If the air-gas be made so that it has a luminosity of exactly 16 candles when burnt in a standard "London" Argand burner at the rate of 5 cubic feet per hour it would be better, as the measurement of the gas used—subject to correction for temperature and pressure—would be the index; but even then it is doubtful whether different burners would give precisely the same result. In such a case, when testing coal gas, no correction need be made either for the standard or for the coal-gas flame, as temperature and pressure would affect both alike. The Author's experience of the system, however, does not dispose him to its adoption in preference to the far more simple "Pentane Argand."

*Harcourt's Pentane Lamp* (*Original Pattern*).—This lamp is constructed to give 1 standard candle light when the wire is set at 63·5 mm., and the flame is at such a height as to touch (but not come above) the wire.

The barometrical correction is as follows:—The wire must be lowered or raised 0·2 mm. for every tenth of an inch that the mercury is above or below 30 inches. The height of the wire, therefore, varies *inversely* with the height of the barometer. When the chimney is used, the perforated plate must be placed on the top of it, and the wire must be

raised 0·6 mm. above what its height would be with the naked flame.

Before using the lamp, fill the upper reservoir three-quarters full of pentane; and, after unscrewing the screw in the box as far as it will go, pour pentane into the mixing chamber till it stands 1½ inches above the horizontal tube leading into the mixing chamber—care being taken not to let any run down the central tube. Open the metal tap and light the lamp; giving it ten minutes to warm the pentane by means of the adjustable metal disc above the flame. While this is taking place, turn the tap gently which leads from the bottle, and adjust the flow of pentane so that it drops slowly from the overflow-nozzle at the same time that the rate of drop from the narrow tube is about twenty drops per minute. The pentane from the overflow-nozzle is caught by the small bottle, and occasionally emptied back into the bottle. The rate of drop from the narrow tube can be adjusted very accurately by means of the screw at the top of the pipe. When once the proper place is found, it need never be moved again.

The height of the flame can be easily altered by screwing the handle of the box, so as to force more or less water into the mixing-chamber. The india-rubber ball should be quite full of water to start with; and the rubber tubing should be wired on to the glass tube to prevent leakage. The pentane should never be allowed to come in contact with the rubber tubing. If the level of the pentane is too high in the mixing-chamber, it will extinguish the flame before it flows down the tube. The metal cock should be occasionally taken out to see if it is free from any water or dirt, as any stoppage in the cock will alter the value of the light.

The height of the adjustable metal disc will depend upon the temperature of the room in which the lamp is working; but when the heat of the disc has been communicated to the mixing-chamber, the disc need not be altered, as the india-rubber ball forms the readiest method of adjusting the height of the flame.

As the platinum wire is apt to be disturbed in moving the chimney, it is well to occasionally verify that the wire is at 63·5 mm., or $2\frac{1}{2}$ inches from the top of the burner, when the engraved scale is set at 63·5 mm., as shown by the upper edge of the pointer.

Note.—Pentane is very volatile and inflammable; and, to prevent waste in pouring it out, it is best to have a rubber or cork stopper through which passes a narrow glass tube, the end of which can be kept closed by a small cork or other form of cap.

The Author's experience with this lamp has been of a varied character. While it gives admirable results when properly adjusted and carefully watched, it cannot be denied that it is a most tedious tool to work with, as the continual adjustment required takes the attention of the observer too much away from the Photometer disc.

*Harcourt's Screened Pentane Lamp* (*No.* 2).—This lamp is constructed as follows:—A vessel, which may conveniently be of glass, and of the form and dimensions of an ordinary spirit-lamp, contains the oil or liquid with which it is fed, and which may conveniently be pentane obtained by purification and repeated rectification from American petroleum. This liquid is so volatile that it is converted into gas within the burner; the wick serving only to bring the liquid to a part of the tube where the heat is sufficient to cause it to evaporate at the required rate.

The illustrations are sectional front and side views of the lamp. The glass vessel A is mounted upon a stand B, provided with levelling-screws C. To the vessel is fitted a cap D surmounted by a tube E, in which a wick is wound up and down by the ordinary arrangement of a double-spiked wheel F turned by a handle. Around the upper part of this tube—whose diameter may be about ¼ inch, and its length 6 or 7 inches—is a second tube G of about 1 inch in diameter

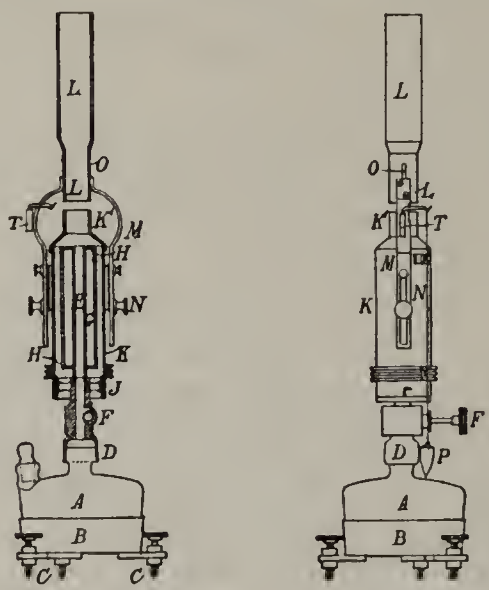


Fig. 19.—Harcourt's Screened Pentane Lamp.

and 4 inches in length, which serves as a jacket to keep more constant the temperature of the inner tube, and to guide the air current upon which the steadiness and brightness of the flame depend. The two tubes are joined by flat plates H above and below, and constitute the burner of the lamp.

Attached to the inner tube by branches is a gallery J, carrying a metal chimney K, which surrounds both the

burner and the lower part of the flame. Above the burner the part $K^1$ of this chimney is reduced to a diameter intermediate between that of the aforesaid outer tube G and the inner tube E of the burner, and terminates at a short distance above the burner. The upper part of the flame is again enclosed by a continuation L of this metal chimney, which is of the same diameter as the lower part, but is enlarged in diameter towards its upper end.

This upper portion of the chimney is connected with the lower chimney by curved metal bands M, conveniently two in number, and sufficiently removed from the flame on either side as not to affect it. Through the space thus left between the upper and lower metal chimneys, the central part of the long flame which the burner produces is alone visible. The attachment of these bands connecting the upper to the lower chimney is adjustable by set-screws N, so that the opening through which the central part of the flame is seen may be made longer or smaller, as desired. By means of a simple adjustment screw, or preferably by means of cylindrical gauges of the same diameter as the tubes which they separate, this opening can be quickly and accurately set to such sizes as will exactly give the light of ½ candle, 1 candle, 1½ candles, or measures intermediate between these, as may be desired.

At opposite sides of the lower part of the upper chimney are two narrow slots O, through either of which the tip of the flame may be seen; and the construction of the lamp is such that the light emitted through the opening between the two chimneys is the same whenever the tip of the flame appears opposite the slot—whether this occurs towards the lower or the upper end.

The bands M connecting the two chimneys are of half the width of the tube that surrounds the flame. When the lamp is vertical so that these bands are in a plane perpendicular to the horizontal bar of the Photometer, the point from which distances are to be measured should be taken in that plane—midway between those edges of the bands which are nearest to the photometric disc, and at the height of the centre of the aperture through which the luminous flame is visible. This point represents the zero of the usual photometric scale.

In order easily to obtain the plane in which this point lies, two slots S are cut in the bands M on the side nearest the disc; and into these slots a flat piece of metal fits, of the same thickness as the depth of the slots. The point from which distances are measured lies on the surface of this piece nearest to the disc.

Suitable attachments are provided for carrying a plumb. line P, to serve in setting the lamp vertical, and for carrying a small piece of coloured glass fitting in the plumb-line socket T so as to stand opposite to the slot O. By reflection from, or direct vision through, this glass, it may easily be observed whether the tip of the flame is within the slot or not. The height of gauges which produce, when burning pentane, a light equivalent to ½, 1, or 1½ standard English parliamentary candles, is respectively 7·5, 16, or 27·5 mm.

This lamp is a great improvement upon the first one devised by the same inventor. In addition to being very constant, it is exceedingly simple to manipulate. It is in reality an improved amyl-acetate lamp, but burning pentane. Like the Methven, only a portion of the centre of the flame is taken for the standard.

The following extracts from M. Monnier's "*Étude sur les Étalons Photométriques*" are such a valuable contribution to the subject of the standards of light, that they form a fitting conclusion to a description of the various standards and their proposed substitutes:—

"On summing up the preceding determinations, one sees that a normal English candle consuming 120 grains of spermaceti per hour is equal to 0·120 normal Carcel.* One normal German candle of paraffin, of which the flame is 50 mm. in height, is equal to 0·34 Carcel. One normal candle of Munich consuming 10·4 grammes of stearine per hour is equal to 0·153 Carcel. One 'Star' candle of five to the packet, consuming 10 grammes of stearine per hour, and giving a flame of 52·5 millimetres, is equal to 5·136 Carcel. One 'Star' candle of six to the packet, under the same conditions, is equal to 0·132 Carcel. The value of the normal Carcel consuming 42 grammes of oil per hour is, therefore, equal to 8·3 English spermaceti candles, 7·5 German paraffin candles, 6·5 Munich stearine candles, 7·4 'Star' stearine candles of five to the packet, 7·6 'Star' stearine candles of six to the packet. The gas of which 105 litres equals one Carcel is equal to 13·2 candles by the English system, and to 14·5 candles by that of Berlin.

"We need not insist on the difficulties that one meets with when comparing the results of first experiments with such variable units, more than on the uncertainty which is attached to the relative value of different standards of light.

"One sees that the system proposed by Mr. Harcourt for

* This does not agree with the Author's and Mr. Sugg's experiments, which make the Carcel to be equal to 9·4 and 9·6 English candles respectively.

representing a luminous standard constitutes an interesting progress towards photometrical measurements; and if the principle of this method were generally adopted, it would be easy to establish experimentally a standard burner representing a definite power of light. This we have done for the use of the laboratory, by regulating the burner to a tenth of a Carcel, in order to simplify the calculations. But as it would be very important that a work of this nature, for its conclusion, should have the unification of photometric measures, it is to be desired that the experiments to be made in this direction should be undertaken with the assistance of experts who have specially devoted themselves to this question in England and Germany, as well as in France. We should perhaps in this way arrive at the realization of an international standard of light, the use of which would permit us to arrange and express, in a language understood by all, the result of the researches made in the different countries."

## CHAPTER VIII.

## AUXILIARY APPARATUS FOR GAS-TESTING PHOTOMETERS.

IN addition to the apparatus described under the heads of Photometers, Discs, and Standards of Light, which are required for all photometrical observations, and constitute the "Photometer" proper, an instrument arranged for testing the illuminating power of coal gas, must be provided with the necessary adjuncts for measuring and controlling the volume of gas to be used for the actual test. As the result depends upon the accuracy with which these operations are performed, it is evident that the implements employed must be of the most accurate description, and must be maintained in perfect working order. The manner in which this is done is the test of an operator's skill, as, however conscientious he may be in going through the routine work of making the requisite number of tests and recording the results, his work will be worthless unless his instruments are, to all intents and purposes, faultless. The exquisite degree of perfection to which a properly-fitted gas-testing station has been brought, invites the most careful attention to every detail. True it is that, after all is done, the errors of candles are sufficient to dishearten

the most persevering; but there is no possible reason why their errors, great as they are, should be added to by those of a careless operator, who should rather strive to neutralize them by redoubled exertion in other directions. The day cannot be far distant when a worthy substitute for the discredited candles will be found, and then those who deem them an excuse for present neglect will never recover their lost ground.

The apparatus necessary to check and measure the flow of gas to the standard burner consists of the following, in the order in which the gas flows through them from the main:—(1) Initial governor; (2) experimental meter; (3) balance governor; (4) regulating cock; (5) burner. To check the working of these instruments, a King's gauge is supplied, which indicates the pressure of gas, as required, at various points in its progress from one instrument to the next.

Each of these instruments is connected by metal tubing, so bent that any water which may be condensed in it, and so would stop the flow of gas, gravitates to the lowest point, at which an outlet-cock is fitted for drawing it off.

As it is essential that a gas examiner should be thoroughly acquainted with the working of his apparatus, so that he may know when it is in good working order, the student will do well to very carefully peruse the following detailed descriptions:—

*Initial Governor.*—This is usually either a "dry" leather or mercurial governor. A "governor" is simply a small gasholder through which the gas passes. The inlet to the holder is partially closed by means of a conical or semi-spherical plug suspended from the interior top of the "bell" of the holder. This plug regulates the flow of the gas by

opening or closing the orifice in the regulating plate as the gasholder rises or falls. A weight placed on the top of the bell fixes the pressure at which the gas is intended to leave the outlet of the governor. If the pressure of the gas on the inlet is greater than that required to lift the bell of the holder and weight, then the bell rises, carrying the regulating plug with it, till such time as the annular opening left between the sides of the plug and the regulating plate is only sufficient to allow of the passage of the necessary quantity of gas to support the bell, and consequently the plug, at the desired point. On the contrary, if the pressure of the gas falls—the supporting power of the gas being then reduced, the bell and attached weights are in excess and fall, and with them the regulating plug, which thus increases the opening and permits a greater flow of gas. From this it is evident that it is necessary, in order to obtain a greater flow of gas, to *add* weights to an *initial* governor, and to *reduce* the weights to diminish the flow. In the later forms of these governors the adjustment by weights has been done away with; a spring regulated by a screw having been found more serviceable—especially with high pressures.

The use of an initial governor is not absolutely necessary; but it is certainly an advantage, as a delicately-adjusted experimental meter will work better under a constant pressure than when exposed to variations of several inches of pressure, as may be the case under special circumstances—such as a direct supply off a high-pressure main, &c.

*Experimental Meter.*—Wet meters only are allowed to be used for official testings; and, if the student is wise, he will under no circumstances allow himself to use a "dry" one for tests which he desires to be of any value when done.

The Author has given this matter no little attention, in the hope of being able to use a dry meter in connection with the "Portable" Photometer; but after repeated trials it was evident that, while the dry meter might be correct now and then, it could never be relied upon for anything like the accuracy so readily obtained with the wet meter. For commercial purposes, the perfect accuracy of the meter is not of so much importance; as, by the provisions of the Sales of Gas Act, 1859, a meter, so far as registration is concerned, is correct if it registers within a range of 3 per cent. in favour of the consumer, and 2 per cent. in favour of the seller of gas. A gas examiner who allowed himself such limits in the adjustment of his meter would not have a very substantial case in the event of his making a report of illuminating power adverse to the gas company.

The meter used for experimental work is of the simplest construction; the principle being that of the Archimedean screw. Ordinary consumers' meters are complicated with adjustments—for variations in the water-line as well as for stopping the flow of gas when, by inattention or accident, the quantity of water has fallen to such a limit that the registration is beyond that laid down by the Sales of Gas Act. The type of meter used for photometrical purposes is that known technically as a station meter, an illustration of which is shown by fig. 20.

Having entered the meter, the gas flows through the bent pipe called the "spout." This is so made as to pass in front of the meter from above the surface of the water into the measuring drum, through an opening (sealed by water) which separates the inlet, or unregistered gas, from the measured gas outside the measuring drum.

The measuring drum is simply a cylinder divided into four separate longitudinal compartments, arranged in the form of four blades of an Archimedean screw. The drum is fixed on a central shaft, with a bearing each end, so as to permit of its being very easily turned by the action of the gas itself when it enters through the spout and passes into those compartments which happen to be above the water-line. There are always two compartments above the water-line at the same time—one filling and the other discharging.

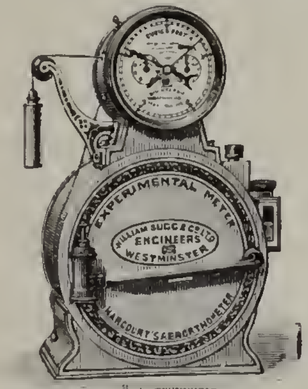


Fig. 20.—Experimental Meter.

The gas entering the measuring drum presses against the underside of the longitudinal division, and turns the drum round for a quarter of a revolution, expelling in the process the gas contained in the chamber immediately preceding it, and so on. Each of the chambers in rotation, as it fills with gas, turns the drum round a quarter of a revolution, and expels the gas from the chamber which precedes it. The meter works very easily, and only absorbs at the utmost 2-10ths of an inch of pressure. Thus, if the pressure of the gas at the inlet of a meter is 1 inch, it will not be less than 8-10ths of an inch at the outlet. The initial measure of the

gas is the capacity of one-quarter of the measuring drum. It is, therefore, evident that these *unit* measures should not be altered in their capacity, or a false indication of the absolute measure will be the result. Thus, if the true water-line of the meter is lowered, the result will be to increase the gaseous measuring capacity of each chamber, and so cause the meter to pass *more* gas than is actually registered by the dial, with the result that the quantity burnt at the standard burner will be in excess of the statutory requirements, and the company will have a corresponding advantage over the consumer in the reported value of the gas. On the other hand, if too much water is put into the meter, then *less* than the proper quantity of gas will be passed, and the results would tell against the company. Hence the absolute care required on the part of the examiner to keep his meter correct.

The Photometer meter indications are read off from a dial on the top of the meter, which is graduated in two scales—one for twelfths of a cubic foot, and the second for smaller fractions. The first is a small dial on the right-hand centre of the larger one. A complete revolution of the pointer indicates that 1 cubic foot of gas has passed through the meter; and each division that 1-12th of a foot has passed. The large dial is divided into five major divisions; and each of these into ten minor divisions. The large hand makes one revolution for each division on the small dial; and consequently twelve such revolutions are required for 1 cubic foot. As there are five major divisions on the large dial, the pointer must pass $5 \times 12 = 60$ of these to indicate 1 cubic foot. The convenience of this arrangement is at once seen when the clock adjustment is brought into

action. This is a carefully-regulated seconds stop-clock, mounted on the top of the meter, and so arranged that the long seconds-hand, making one revolution in a minute, works concentrically with the large meter-hand. When it is desired to ascertain the rate at which the gas is flowing through the meter, the clock-hand is started, and accurately stopped at the top division, marked 5. When the meter-hand arrives at that point, the clock is started at the same moment, so that the two hands start forward simultaneously. At the end of one minute, the clock-hand will have made one revolution, which is indicated by a stroke on a bell. The position of the meter-hand will then indicate the rate at which the gas is passing, provided it be not more than 5 cubic feet, in which case it will have made more than one revolution, and that volume must be added to the figure indicated by the position of the hand at the end of the minute. When the passing rate is exactly 5 cubic feet per hour the two hands should travel at the same rate. The reason for this should be obvious from the foregoing. As 1-60th of a cubic foot in one minute must be equal to 1 cubic foot in one hour, so in like manner 5-60ths in one minute equals 5 cubic feet in one hour, which is the rate usually taken in testing the illuminating power of coal gas.

The height of the water-line is indicated by the water-line box placed on the side of the meter. This box is glazed with glass back and front, and usually has a diamond scratch upon it to mark the level of the water when the meter is registering correctly. The student must not mistake the meniscus formed by the capillary attraction of the glass and water for the correct level. This is shown by the height of the surface of the water, as seen when looking *up*

through the water; the eye then being raised until the surface appears as a sharp line against the glass.

The directions for testing the correctness of a meter by the cubic-foot bottle are so clearly given in the Instructions of the Gas Referees (see "Appendix"), that it is unnecessary to refer to it further than to advise the student to thoroughly master the subject at the outset, as this operation in a great measure forms the backbone of the task of keeping a gas-testing station in order.

The lubrication of the bearings of a meter is provided for by means of a small pipe attached to the back. This is fitted with a screw plug, upon the removal of which a small quantity of oil can be put in the pipe. This operation is not often required; but when a meter shows the slightest sign of undue friction, it should be attended to.

Water is added to the meter, to replace that lost by evaporation, by removing the screw plug at the top of the water-line box. When this plug is fitted (as it ought always to be) with a proper washer, it is not necessary to use pliers to tighten it to such an extent that they are required to remove it again. A firm turn with the finger and thumb should be sufficient—or, at the most, the use of the pliers should be confined to giving it an extra "bite." When one sees the milling on the screw wrenched off, it looks as if a plumber's assistant had been at work instead of a skilful operator.

As a gas examiner should be looked upon as an authority in matters of gas measurement generally, the Author makes no apology for introducing in the "Appendix" the papers named on next page (issued by the Standards Department of the Board of Trade) relating to gas-measuring standards.

1. Revised Regulations as to Gas-Measuring Standards.
2. Description of a Standard Gas-Meter.
3. Standard Gauges for the Connecting-Pipes and Fittings used with Gas-Meters.

These are so full of thoroughly useful information to those concerned in the testing and examination of gas-measuring appliances, that any curtailment of them would only vitiate their value.

*Balance Governor.*—The description of the initial governor will have explained to the student the action of governors generally. The balance governor is merely a more delicate arrangement of the same principles. It consists of a bell floating in water. Above the surface of the water inside the bell are the inlet and outlet pipes. The orifice of the inlet-pipe is partially closed by a conical plug sustained by a rod from the interior crown of the bell, which is supported by a cord or chain from the end of one arm of a balance, the reverse end of which supports a rod, and upon this weights are placed according to the pressure required at the outlet. A weight is suspended from a rod projecting from the centre of the beam for the adjustment of the centre of gravity. The water-line is regulated by an overflow-pipe stopped by a screw-plug in the side of the water-tank. The most convenient outlet pressure to work with is about 7-10ths of an inch of water, which is to be ascertained by a King's gauge, hereafter described (see p. 136). The weights on the balance must be taken off or added to until this pressure is obtained. Upon the correct adjustment of this instrument depends the steadiness with which the gas will pass to the standard burner.

*Regulating or Micrometer Cock.*—This necessary adjunct

to a gas-testing Photometer is supplied in two forms. The original pattern consists of two taps, one placed in front of the other. The lower of the two is actuated by a lever moved by a screw, which enables a very delicate adjustment to be made. The second tap is used for turning the gas full on and off; so that the apparatus is immediately started with the requisite flow of gas as soon as work is commenced. The only precaution necessary in using this form of regulating cock is to see that the tap attached to the lever works smoothly, as, should it stick, the lever will be first bent, and then will, when sufficient tension has been obtained by an excessive movement of the screw, move the tap too far, and thus turn on too much gas. Should this be the case, the plug must be removed from its socket and relubricated. The Author has found this to happen only once.

The second form is a specially contrived tap, the plug of which is hollow, and has two rectangular cuts across the longitudinal axis—one for the inlet of the gas to the plug; and the second, on the reverse side, for its exit. The plug is moved by a lever arm working on a quadrant, which is divided into degrees for facility of adjustment. As in the screw micrometer cock, a second full-way tap is provided for entirely shutting off the gas without interfering with the micrometer tap. Both forms are simple and reliable; but, in the Author's opinion, the former is preferable.

*The Standard Burner.*—The standard burners prescribed for use in testing "common" (14 or 16 candles) and "cannel" (20 candles and over) gas are described in the Gas Referees Instructions. The common gas standard is known as "Sugg's 24-hole 'London' Argand No. 1." The cannel gas standard burner is a steatite batswing burner.

Previous to 1869 the standard burner for common gas was an Argand having only fifteen holes; and before that—viz., from 1851 to 1864—the standard was a brass burner.

The following extracts from the reports (October, 1869, and January, 1870), of Dr. Letheby, then Chief Gas Examiner for the Metropolis form in themselves such an important chapter on this question that no apology is needed for their insertion here:—

"The apparent increase of illuminating power of the common gas at the new stations is wholly referable to the use of the new burner prescribed by the Referees, and which, according to their report to the Board of Trade, gives with the same gas, 16 per cent. more light than the old burner employed at Jewry Street. This is strikingly exemplified in the results of the testings for illuminating power on the six successive days in July, when the change was made from the old to the new burner; and, by way of illustration, I have added, in the following table, the daily returns of the testings of the gas supplied to the City by two other Companies.

*Illuminating Power of Common Gas in Standard Sperm Candles on Six Successive Days in July last.*

| Where tested, and kind of Burner used. | | Gaslight and Coke Company. | City of London Company. | Great Central Company. |
|---|---|---|---|---|
| At Jewry Street with the Old Burner. | July 23 | 14·92 | 14·94 | 15·08 |
| | ,, 24 | 15·40 | 15·13 | 15·85 |
| | ,, 26 | 15·33 | 15·17 | 15·25 |
| | | 15·25 | 15·08 | 15·39 |
| Averages . . . . | | | 15·24 | |

| Where tested, and kind of Burner used. | | Gaslight and Coke Company. | City of London Company. | Great Central Company. |
|---|---|---|---|---|
| At New Testing Stations with the New Burner. | July 27 | 18·39 | 17·90 | 17·49 |
| | ,, 28 | 16·83 | 17·80 | 17·60 |
| | ,, 29 | 16·88 | 18·10 | 17·90 |
| | | 17·37 | 17·93 | 17·66 |
| Averages . . . . | | | 17·65 | |

"Allowance being made for the rapid falling off in power of the Chartered gas, it will be seen that the new burner exalted the quality of the gas to the extent of at least 16 per cent.; for while with the old burner, on the three days preceding the change, the average illuminating power of all the gas supplied to the City of London was 15·24 candles, on the three following days, when the new burner was used, it was returned as 17·65 candles; but since then it has declined to an average of 14·96 candles at the Leadenhall Street station, to 15·63 at the station in Gray's Inn Lane, and to 15·47 at the testing-place in Arundell Street.

"The Company is, no doubt, entitled to the use of the burner which is most suitable for obtaining from the gas the greatest amount of light, provided the burner be, as the 43rd section of the City of London Gas Act, 1868, directs, practicable for use by the consumer; but it is also right that the public should be fully informed of the real value of such burner, when compared with the standard burners already in use, and by which the gas has been heretofore estimated. To this end, as I have stated, the Referees have declared in their report to the Board of Trade that the new burner, which they have prescribed for use, has a photometrical value of 16 per cent. above that of the

old burner. In like manner, on a former occasion, when the steatite burner employed at Jewry Street was substituted for the old brass burner at that time in use, I considered it necessary to state that the change had increased the value of the illuminating power of the gas to the extent of about 11·1 per cent. It appears, therefore, that the burners which have been successively used for testing the gas supplied to this Metropolis have largely increased the photometrical value of the gas; for if the power of the old brass burner, which was commonly employed as the standard burner from the year 1851 to 1864, be called 100, that of the steatite burner which replaced it in 1863 is 111·1, and that of the new burner which is now employed is 128·9. So that *pari passu* with the progress of improvement in the quality of the gas by legislation, there has been a like improvement in the value of the instrument for determining it. In the year 1850, which was the starting point of legislation for this matter, the illuminating power of the gas supplied to the City was fixed at 12 wax candles (equal to 10·3 sperm) by the Act of the Great Central Gas Consumers' Company. In 1860 it was raised to 12 sperm candles by the Metropolis Gas Act of that year; and, in 1868, it was still further increased by the City of London Gas Act to 14 sperm candles. These successive advances are at the rates of 16·5 and 16·7 per cent. on the preceding values—the increase in the values of the burners being at the rates of 11·1 and 16 per cent. In reality, however, as far as the City of London is concerned, the quality of the gas supplied to the public has undergone but little change; for to take the Chartered gas and the Great Central gas as examples, it would seem, from the published returns of the

*Illuminating Power in Standard Sperm Candles of the Common Gas supplied to the City during the last Eighteen Years.*

| Where tested, Kind of Burner, and Date. | | Chartered Gas. | | | Great Central Gas. | | |
|---|---|---|---|---|---|---|---|
| | | According to the Old Brass Argand Burner with 15 holes. | According to the Steatite Argand Burner with 15 holes. | According to the New "London" Argand Burner with 24 holes. | According to the Old Brass Argand Burner with 15 holes. | According to the Steatite Argand Burner with 15 holes. | According to the New "London" Argand Burner with 24 holes. |
| At Old Stations with Old Brass Argand Burners. | 1852. | 12·68 | 14·09 | 16·34 | 13·99 | 15·54 | 18·03 |
| | 1853. | 12·67 | 14·08 | 16·33 | 13·13 | 14·59 | 16·92 |
| | 1854. | 12·72 | 14·13 | 16·39 | 13·28 | 14·75 | 17·11 |
| | 1855. | 12·48 | 13·87 | 16·09 | 13·34 | 14·82 | 17·19 |
| | 1856. | 11·91 | 13·23 | 15·35 | 13·31 | 14·79 | 17·16 |
| | 1857. | 11·19 | 12·43 | 14·42 | 12·91 | 14·34 | 16·63 |
| | 1858. | .. | .. | .. | 12·94 | 14·37 | 16·67 |
| | 1859. | .. | .. | .. | 12·87 | 14·30 | 16·59 |
| | 1860. | .. | .. | .. | 11·73 | 13·03 | 15·11 |
| | 1861. | 12·12 | 13·46 | 15·61 | 11·84 | 13·15 | 15·25 |
| | 1862. | 13·16 | 14·62 | 16·96 | 12·91 | 14·34 | 16·63 |
| | 1863. | 12·89 | 14·31 | 16·60 | 12·36 | 13·74 | 15·94 |
| Average . . | | 12·42 | 13·80 | 16·01 | 12·88 | 14·31 | 16·60 |
| At Old Stations with Steatite Argand. | 1864. | 11·88 | 13·20 | 15·31 | 12·08 | 13·42 | 15·56 |
| | 1865. | 12·43 | 13·82 | 16·03 | 12·45 | 13·83 | 16·04 |
| | 1866. | 12·44 | 13·83 | 16·04 | 12·39 | 13·77 | 15·97 |
| | 1867. | 12·54 | 13·93 | 16·16 | 12·50 | 13·90 | 16·12 |
| | 1868. | 12·67 | 14·09 | 16·34 | 12·65 | 14·06 | 16·31 |
| | 1869. | 13·58 | 15·09 | 17·50 | 13·37 | 14·86 | 17·25 |
| Average . . | | 12·59 | 13·99 | 16·23 | 12·57 | 13·97 | 16·21 |
| At New Stations with New Argand. | 1869. | 11·61 | 12·90 | 14·96 | .. | .. | .. |
| | ,, . | 12·12 | 13·47 | 15·63 | .. | .. | .. |
| | ,, . | 12·01 | 13·34 | 15·47 | .. | .. | .. |
| | ,, . | .. | .. | .. | 12·81 | 14·23 | 16·51 |
| Average . . | | 11·91 | 13·24 | 15·35 | 12·81 | 14·23 | 16·51 |

quality of the City gas during the last eighteen years, that the illuminating power of it in 1852 was nearly the same as it is at the present time. This will be apparent from the preceding table, which exhibits, year by year, the power of the gas, according to the value of the three burners which have been successively used for testing it; and it will be noticed that from 1851 to 1857, the average illuminating power of the Chartered gas was 12·28 candles, and of the Great Central, 13·33—the power in 1869 at Jewry Street being, according to the same mode of estimating it, 13·46 and 13·39 candles respectively. But when tested with the new burner at the new stations, the value of the Chartered gas, as represented in the former cases by the old brass burner, has been but 11·61 candles at Leadenhall Street, 12·12 at Gray's Inn Lane, and 12·01 at Arundell Street.

"In my last quarterly report, I stated that the photometrical burners, which had been used during the last twenty years for estimating the illuminating power of gas, had very different values; and I submitted a table of the comparative power of the gas according to the burner used. The following is a like statement of the average illuminating power of the common gas at the different stations according to the values of the different burners."

| Name of Station. | Old Brass Burner (1852 to 1863). | Sugg's Steatite Burner (1864 to 1869). | Sugg's New "London" Burner (1869). |
|---|---|---|---|
| Arundell Street, Common Gas | 11·63 | 12·92 | 14·98 |
| Leadenhall Street Do. | 11·47 | 12·75 | 14·78 |
| Gray's Inn Lane Do. | 12·18 | 13·53 | 15·00 |

*King's Gauge.*—This instrument forms the key to the accurate working of the apparatus generally, as by its means irregularities at any point between the outlet of the initial governor and the burner are readily detected. It is the delicate gauge already described under the head of "Jet Photometers," but without the jet and the case necessary for steadying the flame. The inlet is connected with the pipes on the inlet of the meter; with the inlet of the balance governor, and consequently the outlet of the meter; with the outlet of the balance governor, or inlet to the regulating cock; and with the outlet of the regulating-cock, and consequently the supply to burner, or "point of ignition." When testing the photometer meter by the cubic-foot bottle, if the pointer on the dial plate—generally placed by the side of the gauge—is adjusted to "after meter," or, in the older forms, the tap on the brass pipe, marked "outlet of meter," is opened, and the outlet-tap of the gauge itself also opened, the air passed into the meter from the bottle will flow into the room without passing through the rest of the apparatus.* When a gas-testing Photometer and the auxiliary apparatus is properly adjusted for work, the pressure on the inlet of the meter is regulated to a little over an inch—say, 12-10ths—which is reduced by the friction of the meter to about an inch. The balance governor is adjusted to reduce this to about 7-10ths, in order to allow a good working pressure for the micrometer cock, which further reduces the pressure at the point of ignition to about 3-10ths of an inch. Some burners, although made with the utmost possible care,

* According to the most recent "Instructions" of the Gas Referees, *coal gas* must be used for testing meters, and the gas so used burnt in the standard burner at the rate of 5 cubic feet per hour.

require rather more than this quantity to pass 5 cubic feet per hour. But, whatever it is, it is soon found by trial; and the operator is furnished with a guide for adjusting the regulating-cock, after cleaning and testing the meters, governors, &c.

Care should be exercised not to allow the water in the tank to fall below the proper quantity, which is ascertained when the gas is shut off, and the outlet-tap on the side is open, by unscrewing the plug in front of the tank, when the water should be at such a height that a small quantity will flow out. If this is not the case, water should be added through the opening covered by the plate at the top, through which the string sustaining the bell passes, until it just trickles out through the plug aperture. When this has been done, the plug is screwed gently but firmly in its place; and the pointer adjusted on the pivot until it exactly indicates zero.

## CHAPTER IX.

## EXAMINATION AND ADJUSTMENT OF A GAS-TESTING PHOTOMETER.

ALTHOUGH the description of the various Photometers and auxiliary apparatus contains nearly all that is requisite under this heading, it may be useful to briefly describe the regular operations necessary to keep the instrument and all its parts in proper order; as neglect of a systematic periodical examination will undoubtedly lead to erroneous results, which unfortunately have a knack of showing themselves at the very moment when they are least wanted. The Instructions of the Gas Referees prescribe that the meters should be tested at least once a week; and when the time which should always be set apart for this operation arrives, it is as well for the Examiner to test the rest of the apparatus—an act to ensure him from needless anxiety in the case of his obtaining results likely to lead to legal proceedings, as no after-thought can compensate for the misery of uncertainty and vain regrets. Above all things a Gas Examiner should be *systematic*.

In the following description of the plan adopted by the Author, it is assumed that the exactness of the Photometer scales, the position of the opposed lights, the correctness of

the cubic-foot bottle, and other permanently adjusted apparatus, have been ascertained once for all; and that the working of the instruments is all that remains to be tried.

*Syphons.*—The pipes under the Photometers are to be cleared by opening the taps on the bent syphon-pipes until all water condensed therein drains out, when the taps are to be carefully turned off.

*Meters.*—The water-line is to be noticed; and, if incorrect, the proper quantity of water must be added, or removed, until the true level is obtained. In the case of meters which have been repaired, the original line on the glass is sometimes incorrect; and a new one is best indicated by a mark on the case by the side of the glass. When once this is done, it will remain true until the meter has again been to the makers for further repairs, when the true line must be again ascertained. The meter is then tested by the cubic-foot bottle according to the Instructions laid down by the Gas Referees (see "Appendix").

*The King's Gauge* has now to be seen to; and the water-line and pointer, if necessary, adjusted as already described.

*The Balance Governor* is next examined, and water added if required.

*Test for Leakage.*—Remove the standard burner from its support, which is done by lifting it out of its socket; and screw on the cap provided for this purpose over the pipe. Then turn the gas full on; and note the long hand of the meter. At first a small quantity of gas will pass, until the pressure is equalized, after which the meter-hand should remain steady. This being satisfactory the burner is replaced and the gas lighted.

*King's Gauge.*—Next test the apparatus by means of this

gauge. Open the outlet-tap on the side, and shut off all inlet-taps, when the pointer will fall to zero. Shut off the outlet-tap, and open that indicated as "Inlet of Meter." The pointer should indicate a little over 1 inch. In case this should not be so, adjust the weights, or screw, on the initial governor under the bench until the proper pressure is obtained, when the inlet-tap to the gauge is shut off. Next open the tap marked "Outlet of Meter." The pointer should fall back from one to two-tenths. If it is more than this, probably the meter-bearings require a little oil, which is applied by putting a few drops in the slanting pipe at the back of the meter. Then shut off the "Outlet of Meter" tap; and open that marked "Outlet of Governor." The pointer should again fall back, and indicate from 6-10ths to 7-10ths. In case it does not do so, obtain that pressure by increasing or decreasing the weights on the balance governor, which will then work satisfactorily. In like manner ascertain the pressure after the regulating-cock, or "point of ignition" as it is sometimes called. As before stated, this is a quantity which slightly varies with different burners; but, when once ascertained, it is a useful guide.

If these operations are carefully performed, the gas portion of the apparatus will be known to be in good order, and the tests may be proceeded with, after the following further examinations have been satisfactorily made.

*Standard and Meter Clocks.*—These are to be carefully compared over a period of ten minutes. The error of the meter clock should not exceed two seconds in that time. If it is more than this, the glass face is removed and the regulating index slightly altered, until on further trials the two clocks work together.

*Candle-Balance.*—This should be clean and free from dust and droppings of sperm from the candles, especially under the candle-holder, as a very slight quantity is sufficient to cause the balance to "stick," and so give erroneous results. The candles are to be placed in position and lighted, when they must be counterpoised and the time noted for the candle end of the balance to rise and come to rest. This should not exceed five or six seconds. If it is greater or less than this period, the balance must be adjusted by screwing the ball on the top up or down until on further trials the proper rate is attained.

*The Disc.*—After having adjusted the gas-flame to about 5 feet per hour, and placed the candles in good burning condition in the balance, proceed to take a series of readings; and then reverse the disc and again read. This is to be done several times; and the mean results of the readings, with the disc in each position, noted. If the disc and mirrors are in good order, the results should be alike; but, if they disagree, a new disc is to be put in position, and the operations repeated, until a good disc is obtained. In the case of an Evans Photometer, these readings should be made with the two end doors open.

*The Velvet Curtains, &c.*, of the Photometer should be kept free from dust, which is a great reflector of light, and a dreadful tell-tale of the reliance to be placed on an operator's work.

# CHAPTER X.

## COLOUR PHOTOMETRY.

THE relative luminous values of coloured lights, and of the tinctorial characters of the numerous pigments and dyes, have long formed a question of no little importance. The rapid strides in the development of the art of dyeing—due to the introduction of the aniline dyes—have raised the question to one of a technical as well as scientific value. An account of the methods suggested at various times for estimating the values of colours will, therefore, not be out of place in a work on Practical Photometry.

*Composition of Colours.*—Colours are either simple or compound. The simple colours are those of a pure spectrum; and compound colours are produced by the mixture of two or more of these simple ones—as in the instance of Newton's rings, or the fringes produced by diffraction. Compound colours may be similar to the pure shades of the spectrum, but are rarely identical with them in the impressions which they produce on the visual organs. The resultant tint, produced by the mixture or superposition of any number of simple colours, may be investigated by one of the following methods.*

1. By mixing coloured substances in fine powder. This

* Watts's Dictionary of Chemistry, Vol. III. Article: "Light."

method, however, yields only dull and deadened colours, in consequence of the large quantity of light absorbed. Moreover, the rays reflected from the surfaces of the two substances are mixed with rays which have penetrated to a certain depth, and have been there reflected ; so that the tint which would be produced by the mixture of the rays directly reflected from the surface is modified by colours arising from absorption.

2. By covering with black paper certain portions of a revolving disc tinted with the colours of the spectrum ; the colour perceived being that which is produced by the composition of the remaining spectral colours.

3. By tinting two pieces of paper with the colours whose composition is to be studied, laying them on a black table, setting up between them a plate of unsilvered glass, and placing the eye so that the image of one of them seen by reflection may coincide with that of the other seen directly through the glass (Helmholtz).

The second and last of these are preferable to the first; the only source of error affecting them being the deviation of the artificial colours from the pure tints of the spectrum. The only way of attaining perfectly accurate results is to operate directly on the rays of the spectrum itself, as in the following methods :—

4. By intercepting some of the coloured rays as they emerge from the prism, and bringing the rest to a focus by an achromatic lens. This is the essential feature of Captain Abney's "Colour Photometer."

5. By receiving the rays of the spectrum on a row of plane mirrors capable of being adjusted so as to reflect any required rays to the same point on a screen.

6. Helmholtz's method is the most exact of all. It consists in viewing through a vertical prism two narrow slits forming a right angle, and each inclined 45° to the edge of the prism. The prism being placed about 4 yards from the slits, and in the position of least deviation, two spectra are seen, in which, with the aid of a telescope, the principal fixed lines may be distinguished parallel to the slits. These two spectra are partly superposed; and the dimensions of the slits must be such that each coloured band of one spectrum shall cross all the coloured bands of the other. (Compare with Captain Abney's "Colour Photometer," p. 157.)

To find the effect produced by the combination of two colours, the telescope is directed so that the intersections of its crossed wires are projected on the combination to be examined; and the eye is placed behind a small hole in a screen, at 60 or 80 centimètres from the telescope, so that it may perceive only a very small space around the point of the intersection. The compound tint required may thus be examined without being affected by the neighbouring colours. By covering up the two slits successively, the simple colours producing the combination may be seen.

In order to vary the relative qualities of light in the component colour, the prism was inclined in such a manner as to bring it more nearly parallel with one of the slits; the spectrum of this slit was thereby brought nearer to the rectangular form, and its colours were more condensed, while the contrary effect was produced upon those of the other. By adding a third slit, the effect of combining the three colours may be observed. By these means Helmholtz has obtained the following results.

1. The compound tint formed by the mixture of two simple colours is sometimes to a certain extent identical with a simple colour of the spectrum; but in many cases it is different from them all. For example, when the greenish-yellow and the greenish-blue of the spectrum are mixed together, a green is produced much darker than that of the spectrum. This last green, as well as the violet and red of the spectrum, cannot be exactly imitated by the mixture of any colours.

2. The tint produced by the union of three simple colours of the spectrum is different from that which would be obtained by combining any one of them with a simple colour which in some degree resembles that formed by the mixture of the other two. For instance, the combination of the red and bluish-green of the spectrum produces *yellow*; but red, when mixed with the bluish-green resulting from the union of green and indigo, will produce *white*.

3. There are many combinations of three colours which form white.

4. With three colours only, it is not possible to obtain satisfactory imitations of all the colours of the spectrum; the number of simple colours required for the purpose being at least five—viz., red, yellow, green, blue, and violet. Hence, according to Helmholtz, the theory of three primary colours proposed by Brewster does not rest on a satisfactory foundation; and if it is possible to obtain something like an imitation of all the spectral colours by the mixture of three coloured powders, the result must be attributed partly to the want of brightness in the colours used, and partly to the circumstance that the resulting compound colours have not generally been directly

compared with the colours of the spectrum from which, in most instances, they differ considerably. The three colours hitherto adopted—viz., red, blue, and yellow—are not even the three best adapted to the purpose. Better results are obtained with red, green, and violet; but, even then, the imitations are far from perfect.

From the exhaustive experiments conducted by Airey, Helmholtz, Maxwell, and others, it may be inferred that it is impossible to decompose the colours of the spectrum by absorption any more than by refraction; also that the colours, as Newton supposed, are simple; and that to each colour there corresponds a definite degree of refrangibility.

*Complementary Colours.*—This name was applied by Newton to any two colours which by their mixture produce white light—such as green and red, orange and blue, yellow and violet.

Helmholtz made some very remarkable experiments on complementary colours by throwing the pure spectrum, formed by a prism and achromatic lens, on a screen pierced with two narrow slits parallel to the edges of the prism, and capable of being brought close together at pleasure. The two homogeneous coloured pencils thus obtained are received on a lens which condenses and brings them to a single focus on a white screen placed at a suitable distance. By this mode of experimenting, Helmholtz has shown that there exists an infinity of binary groups of colours, which, when united in *due proportion*, produce a perfect white. With the exception of pure green, every simple colour of the spectrum is complementary of another simple colour. By varying the breadth of one of the slits, the relative intensities of the two coloured beams could be altered;

and it was thus found that the proportions between the intensities of two coloured beams, which produce white light by their combination, sometimes vary with the intensity of the incident light. This is shown by the following numbers:—

| Group of Complementary Colours. | Ratio of intensity of the second colour to the first | |
|---|---|---|
| | Bright light. | Faint light. |
| Violet—greenish-yellow | 10 | 5 |
| Indigo—yellow | 4 | 3 |
| Blue—orange | 1 | 1 |
| Greenish-blue—red | 0·44 | 0·44 |

The same mode of experimenting led to the unexpected conclusion that the mixture of the blue and yellow rays of the spectrum produces white; whereas the mixture of blue and yellow liquids or powders always produces green. This result is confirmed by painting two paper discs, one with chromate of lead or gamboge, the other with cobalt-blue, and making the reflected image of the one coincide with, or overlap the direct image of the other, as in Method 3 (p. 143). The compound image thus seen is white. With the yellows above mentioned and artificial ultramarine, the white has a slight reddish tinge; with Prussian-blue, a greenish tinge. The production of green, by the mixture of blue and yellow powders or liquids, arises from partial decomposition of the light by absorption, as explained at p. 145.

*Nomenclature of Colours.*—The terms employed to designate different shades of colour are for the most part very indefinite, being sometimes borrowed from natural objects or substances, sometimes from the names of inventors of preparations which exhibit the particular colour, and from various other sources more or less fanciful. The colours

of minerals are usually distinguished by comparison with familiar natural objects which they more or less resemble. Thus, blues are specially distinguished as azure, violet, lavender, smalt, indigo, and sky-blue; greens, as verdigris, celandine, mountain, leek, emerald, apple, grass, asparagus, olive, oil, and siskin-green; yellows, as sulphur, straw, wax, honey, lemon, ochre, wine, cream, and orange-yellow; reds, as aurora or roseate, hyacinth, brick, scarlet, blood, flesh, carmine, rose, crimson, peach-blossom, columbine, and cherry-red; browns, as cloves, hair, broccoli, pinch-beck, wood, and liver-brown; greys, as pearl, smoke, ash-grey, &c.

To obtain greater accuracy in the nomenclature of colours, Chevreul has devised the following scheme. In the first place he assigns definite meanings to the terms "tint" and "shade or tone"—denoting by tint the result of mixing pure colours in various proportions, and by shade or tone the result of mixing any tint or simple colour with black or white, so that each tint is susceptible of an infinite gradation of shades. A tint is weakened or *lowered* by the addition of white; and strengthened or *heightened* by the addition of black. Colours mixed with black are said by painters to be deadened—they reflect less light. In fact, if a coloured surface be less and less illuminated, it becomes continually darker, and ultimately black. This effect is experienced at the close of day; all the colours then becoming darker, and turning towards black.

*Chevreul's Chromatic Circle.*—Chevreul has formed a table of 72 tints passing gradually one into the other, and each modified by 20 shades—some produced by admixture of white in various proportions, and the rest by admixture of black. Imagine a circle divided into 72 equal

sectors. Three equidistant sectors are coloured respectively with *red*, *yellow*, and *blue;* and at equal distances from these three colours are placed those which result from their mixture two by two—viz., *orange* between red and yellow; *green* between yellow and blue; and *violet* between red and blue. Then between these six are placed the intermediate tints; and so on till the whole 72 are complete. Each of these 72 sectors is then divided into quadrangular segments by 20 concentric circles, and in the segments thus formed are placed the shades belonging to each colour. At the centre is a small white circle, starting from which each tint becomes gradually deeper by the continual abstraction of white, till the pure tint is attained; and beyond this the shade is continually deepened by the addition of black till the circumference is reached, which is quite black. There is thus a circular series of segments containing the pure tints with their maximum of intensity; and starting from these, the shades in each sector become weaker towards the centre, and stronger towards the circumference. The series of colours contained in any one sector forms a gamut of shades of the corresponding tint. Each circle of segments contains the 72 tints corresponding with the shade of that circle. We have thus a diagram of 1440 colours, forming types near enough to one another for the requirements of the arts. It would be useful also to add the gamut of white—that is to say, the series of grey shades from white to black. Such a diagram constructed with permanent colours, on painted porcelain for example, is capable of rendering important service in the arts, by affording a standard nomenclature of colours, which may be designated by the numbers of the sector, and the circumference in

which they occur; but, as will presently be seen, it is immeasurably surpassed by the tintometer of Mr. Lovibond.

Lecocq arranges the coloured segments in a different way. He divides the surface of a sphere into quadrangular spaces by means of meridians and parallels. The pure colours are placed at the equator, and each of them becomes darker along the course of its meridian towards one pole, at which there is a black spot; and lighter towards the other pole, where there is a white spot. It would be more convenient to use a cylinder having one of its bases bordered with black, the other with white, and the pure colours arranged round a zone in the middle. The cylinder might also be developed on a plane, and the whole series of tints and shades thus presented to the eye at once. By repeating at one end of the diagram thus formed some of the gamuts from the opposite end, each gamut will be placed next to those which differ from it the least. In this form the diagram is more easily constructed, especially if it is to be made in porcelain.

*Masson's Electro-Photometer.*—As well as being applicable for ordinary photometric observations, this apparatus has the advantage of admitting the comparison of lights of different colours. It consists of a circular disc divided into white and black sectors of equal size, and set in motion by clock-work at the rate of 250 to 300 revolutions in a second. If it be then illuminated by a constant source of light, such as a lamp, it appears of a uniform grey tint, in consequence of the duration of the visual impression on the eye. But if it be illuminated by an instantaneous light, such as the electric spark, the black and white sectors become distinctly visible,

and appear as if they are fixed, because they have not time to move through a sensible angle during the extremely short interval for which the spark continues. If now the intensity of the light afforded by the spark be gradually diminished, by removing it to a greater distance—the source of constant light still remaining, the increase of illumination which the spark affords to the disc ultimately becomes too feeble to render the sectors visible, so that the disc only continues to exhibit a uniform grey tint. The relative intensities of the constant and instantaneous lights at which this limit is attained evidently depend upon the number of sectors and the velocity of revolution.

The relative intensities of two electric sparks are the same in proportion as the squares of the distances to which they must be removed from the disc to cause the sectors to disappear, the disc being illuminated by a constant light. On the other hand, to use the instrument for comparing the intensities of two continuous lights, a succession of electric sparks is made to pass in front of the disc, and one of the constant lights is made to approach it till the sectors cease to be distinguishable. The same experiment being then made with the other light, the intensities of the two are in the same ratio as the squares of the distances thus determined. This system, however, cannot be recommended in preference to the usual photometer fitted with the Author's star-disc.

*Lovibond's Tintometer.*—On the 26th of December, 1887, Mr. Lovibond, of Salisbury, read a paper before the Society of Dyers and Colourists, at Bradford,* in which he

* See *Journal of the Society of Dyers and Colourists*, Dec. 26, 1887 No. 12, Vol. III.

described "The Tintometer—a new instrument for the analysis, synthesis, matching, and measurement of colour."

The system adopted by Mr. Lovibond is founded on the fact that while superposition of the *spectral* colours yields only increased brilliancy, constant additions of *pigmentary* colours build into darkness; and it is thus described by him: The apparatus, apart from stands and reflectors, may be divided into two essential parts. The first is an instrument giving two fields of view under exactly similar monocular conditions, freed from the errors arising from unequal side-lights, and the different power of distinguishing which may exist in the eyes of the observer. The second part consists of standard sets of coloured glass-slips; the glasses composing each set being all of the same colour, but regularly graded for depth of tint. Each series of one colour bears a denominational or *colour number;* the depth of tint is also noted by an additional *tint number*, engraved on the slip below the colour number.

The use of several superimposed glasses from a single set produces a depth of tint represented by the aggregate of tint numbers on the glasses used; while glasses from several sets produce a composite colour, and the exact proportion of each component colour can be read off. The range of colour obtainable by these compounds is very wide, and apparently only limited by the purity of colour in the glass acquirable for the standards.

The instrument consists of a tube divided by a central partition B (Fig. 21), which terminates at the eye-piece C in a knife-edge; this being inside the range of vision, is not seen when the instrument is in use. At the other end of the instrument are two apertures—D,D—of equal value, alterable in

size and shape by means of diaphragms. The two apertures are here divided by the thick end of the central partition B, which, together with the sides, is recessed by grooves in order to hide the edges of the standard glasses and of the vessels placed in the tube for observation. The top is provided with slots in line with the grooves, which admit and guide the coloured standard glasses into the tubes. The bottom, sides, and central partition are carried beyond the top, forming chambers in continuation of the tubes to hold the gauged glasses of liquid. A friction rod with clips is fitted on each side, to retain the vessels of liquid in position; and the whole is arranged in such a way that the only light

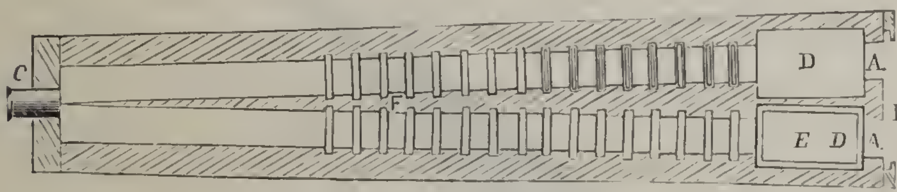


FIG. 21.—LOVIBOND'S TINTOMETER.

which can reach the eye of the observer must pass in equal quantities through the object in one tube, and the standard glasses in the other.

For measuring colour in opaque objects, the instrument is fitted to a hinged stand (Fig. 22), capable of being placed at such an angle as reflects the light from the whitened bottom and sides up the tubes to the eye, so that on looking through the eye-piece two equal white fields of view are seen. The object to be measured is placed on the stage under one tube, and the standard glasses worked in the other, against the white background. When the colours of two objects are to be compared with each other, they are

placed one under each tube respectively, and standard glasses added to the lightest in colour until both sides are equal, when the difference between them, either in colour or tint, can be read off.

In any case where the surface of the object has a special influence on the character of the light reflected from it, as from velvet, satin, cotton, yarns, powders, &c., the background against which the glasses work must be white, but similar in texture to the sample under examination. Such white should, however, be first measured to see how far it

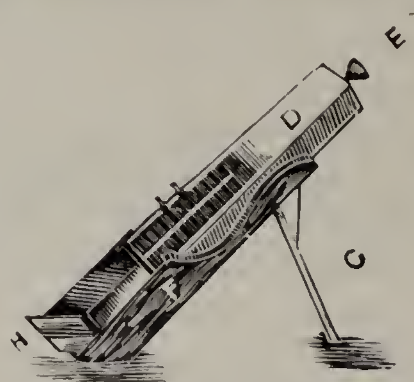


Fig. 22.—Lovibond's Tintometer.

takes its departure from the standard white chosen for a common reference. Mr. Lovibond finds pure plaster of Paris a convenient one for the purpose.

In making a scale, the first step, after obtaining glass slips of as many tints in one colour, is to give that colour a denominational colour number; the principle to be observed in building the scale is to take a very faint tint for the starting-point or unit, and place two of these, which must be exactly equal, in one side of the instrument, matching them by a single glass on the other

side. This glass is of two-unit value. To it is next added one of the first two selected, and these should be matched by another glass, which is then of three-unit value; and so on, proceeding by the addition of a tint at a time, as far as the glass available will permit, or the colour is built into darkness. Each glass is marked with its colour number, and, below that, with the number of units of tint which it represents. The regularity and correctness of a scale so constructed can be easily tested by cross-checking its own number.

In fixing the depth of tint to be assumed for the unit of departure, it was evident that, the eye being sole judge of difference, and noting that the powers of differentiation decreased as the tint increased in depth, the tint should be as light as was consistent with the possibility of the distinguishable addition of a single unit in the deeper shades; while for lighter shades, where the power of differentiation is keener, the divisions of the tint-unit may be effected, if necessary, by decimals of the original unit of value.

An effort was also made to find, as a basis of common value, a unit applicable to the measurement of all colours; but the unequal absorption of light by the different colours, and by the various makes of glass, proved an effectual barrier—some building into darkness at a much quicker rate than others. For instance, in colours of a primary character with a medium north daylight, red requires 77 of its own units, blue 222, and yellow 239. The differences are still greater in more composite colours.

From these truths, two governing facts were deduced—first, as each colour had its own rate of absorption, so it must

have its own progressive unit, which is not applicable to any other colour; and, second, that in building up a scale, the glasses composing it must be of the same make—that is, of the same composition, each coloured with the same material.

This enforced limitation of the value of each unit to its own colour is, as regards a common basic unit, restrictive, but beyond that point very expansive, permitting the unlimited addition of new colours for standards, without altering the value of those already in use, or in any way interfering with the value of the registered work previously done with them.

The vessels for holding liquids, whose colour is to be measured, are gauged to contain a body of liquid varying in thickness from 1-16th of an inch for dark ones up to 2 feet for very pale ones. With the latter, the amount of blue colour in distilled water can easily be measured. Longer lengths than 2 feet can be made if necessary. When the 1-16th of an inch stratum is still too dark for close reading, a lower degree of tint can be usually obtained by proportional dilution. The vessels are made in brass, with colourless glass ends, for neutral and alkaline solutions, and entirely in glass for acids and corrosive liquids.

When dissimilar substances are to be compared, the intensity of the light used becomes an important factor, and extremes cannot be ignored; for, whilst there is considerable range of daylight within which the judgments of the eye are uniform, care is required outside these limits, and practice soon shows at what point the work must be abandoned from insufficient or too much light.

From the foregoing description, it will be seen that, when either a liquid or a solid colour has been matched with the standards, the numbers on the matching glasses afford a complete record of the several colours and the tint-units constituting the colour equalled. Mr. Lovibond claims that the invention of this instrument places a new power in the hands of investigators in many departments of science, as well as of those who are interested in the question of colour alone, opening up new channels of research which hitherto have been wholly impracticable, or only possible on narrow lines and under great difficulties. The Tintometer has already been put to practical use for the valuation of dyes, sugar, flour, oils, malts, beers, wines, waters, and to many laboratory colorimetric processes, such as the estimation of carbon in steel, nesslerizing, &c.

Mr. Lovibond is certainly entitled to no little credit for so providing a convenient instrument to readily and accurately measure and register colours of any description and shade, which can thus be reproduced at any future period with absolute certainty.

*Captain Abney and Major-General Festing's Colour Photometer.*—On March 24, 1886, Captain Abney, F.R.S., and Major-General Festing, R.E., laid before the Royal Society* an account of the method used by them in measuring the relative illuminating intensities of different parts of the spectrum. For the purpose of comparing the visual intensity of two rays of different colour, they used the method of the close juxtaposition of small patches lighted from different sources, as in Rumford's system of Photometry. To

* See "Philosophical Transactions of the Royal Society," Part II., 1886.

obtain the comparison-coloured ray, the light from an electric-arc lamp was passed through a spectroscope—a photographic camera being used in place of the observing telescope; different portions of the spectrum were then isolated and made to fall in a patch on a white screen by means of a lens. The arrangement is thus more particularly described: The light was focused on the slit of the collimator by a condenser filling the collimating lens; and after passing through two flint prisms of medium density—each at an angle of 62°—it fell on the lens of a camera, which brought the spectrum to a focus on the ground-glass screen. A sliding slit, made in a card, was substituted for the dark slide; and the patch of light was formed, by being collected through a double-convex lens, on a white surface placed at about 4 feet from the sliding slit. In front of the white surface was set an upright rod about ½ an inch in diameter, to intercept the light from the two sources. A slide, carrying a candle or an amyl-acetate lamp for the comparison-light, moved on a lath of wood, to which was attached a scale commencing at the screen. When a patch of light of any desired colour was thrown on the white screen, the comparison-light could be moved along the scale till the luminosities appeared to be equal. The readings, though at first somewhat difficult, were afterwards rendered very satisfactory by the plan of "oscillation"—*i.e.*, by oscillating the slide gently between points where first one shadow and then the other was palpably too dark; the vibrations became gradually shorter until the point of balance was determined.

The position of the spectrum was fixed by means of burning different salts in the arc—those of magnesium and of lithium being found most convenient. A piece of ground

glass being placed against the slit in the focus of the spectrum, it was easy to see when the position of the slit corresponded with that of any line. The situations of these lines being obtained by the reading of the scale on the slide, wave-lengths for different parts of the spectrum could be interpolated. For the purpose of obtaining a uniform whiteness on the receiving screen, it was coated with zinc-oxide mixed with very pure white gelatine, dissolved in as small a quantity of water as possible, and used sparingly. The portion of the screen employed was limited to a space of about 2 inches square, by a sheet of black paper with a hole of that size cut in it being placed close in front of, and in contact with, the screen. By this method, the authors have proved that the impression of a mixed light on the eyes is equal to the sum of the impressions of the various components of the light.

In a second contribution to the Royal Society * by the same authorities, the following description was given of a modification of the above, devised by Captain Abney, for the measurement of the colour of various water-colour pigments:—The collimator prisms and camera were at first kept as in the colour photometer; but for the camera-lens was substituted one divided into two equal segments, which could be centrally separated, as in a heliometer. The light coming through the last prism fell as a square patch on this divided lens; and the two segments were separated so that two spectra fell on the focusing screen, one above the other. A slit in a card was then passed across this double spectrum, and any required ray was isolated. A

* See "Philosophical Transactions of the Royal Society," Vol. CLXXIX (1888).

right-angled prism, attached by a rod to the top half of the slit, reflected the ray from the top spectrum to one side; whilst the ray of the colour from the bottom spectrum traversed the slit unimpeded, and fell on the lens, forming a patch of monochromatic light on the screen. The reflected ray was again reflected by a mirror, and fell on another lens, by which a similar patch of monochromatic light could be made to fall over the patch first formed. Each of these monochromatic rays cast the shadow of a rod placed in front of the receiving-screen, and the shadow cast by each spectrum was illuminated by light of the same colour coming from the other. To measure the value of a coloured paper, the screen was made half with a white card and half with the coloured paper. The shadows were made to touch at the intersection of the card and coloured paper. In front of the light which illuminated the shadow cast on the white card was placed a motor rotating movable sectors. Two methods presented themselves of equalizing the illumination of the shadows—first, by moving the slit across the spectrum, whilst the sectors rotated with a fixed aperture; or, secondly, by placing the slit at known places in the spectrum, and equalizing the illumination of the shadows by altering the aperture of the sectors. The latter method was most usually adopted. This plan of producing two spectra was subsequently modified by fixing a double-image prism behind the collimating lens. This was so adjusted that, when the central half of the collimator-slit was used, the two spectra, although of the same length, were separated by one-eighth of an inch on the focusing screen. The ordinary camera lens was employed. The reflecting apparatus was also

slightly altered by substituting for the fixed reflector a second right-angled prism attached to the card, so as to reflect the light through the second lens.

The adjustment of the instrument, when using the double-image prism, required care; and the following plan was adopted :—The whole of the slit of the collimator was illuminated by light from the arc in which lithium and sodium were vaporized. The two spectra now overlapped, since the separation of one-eighth of an inch was only obtained when the slit was one-fourth of an inch in height. The bright lines of the lithium in the two spectra were then made to coincide by turning the double-image prism. The central portion of the slit in the collimator was then used, and the slit in the card passed through the two spectra. If the collimator slit was properly adjusted in the vertical, and a bright line in one spectrum traversed the centre of (say) the top part of the aperture in the card, the same bright line in the other spectrum ought to traverse the centre of the bottom part of the aperture. If this were not so, the collimator was re-adjusted, and the same operation gone through. To make doubly certain that the adjustment was correct, the direct and reflected rays from different parts of the continuous spectrum of the positive pole were made to form superposed patches on white card, and the shadows of a rod were cast by each so as to touch. The rotating sector was placed in front of the brightest, and the illumination of the two equalized. If the same aperture of sector equalized the illumination throughout the spectrum, the adjustment was considered as complete; if not, a new adjustment was made till such was the case. It was found

in practice that a very good adjustment could be made by noting if the colours of the two shadows were of exactly the same hue, more especially in the transition between orange and green, and in that from the blue-green to blue. The slightest departure from true adjustment invariably showed itself in these two parts of the spectrum. Great care must be taken to exclude all extraneous light from the receiving screen.

The great point in measuring accurately was to adjust the luminosity so that the eye could readily distinguish any small differences in the brightness of the illuminated shadows. This was effected by altering the width of the slit in the collimator from time to time. When the brightest part of the spectrum was under measurement, the width was about $\frac{1}{150}$th of an inch; and, when the least luminous parts, it was opened to about $\frac{1}{30}$th of an inch. The slit in the card remained invariable; being about $\frac{1}{25}$th of an inch in width. The screen was placed 3 feet from the slit card.

By means of this apparatus, gas and sky light were compared with the electric light. The light diffused through a cloud on a cloudy day in April was found to be almost exactly similar to the light of the electric arc; and, in fact, to be degraded sunlight. The light reflected from various metals was likewise examined. It was also found that the light reflected from or transmitted through ordinary pigments is of the same character.

# CHAPTER XI.

## STELLAR PHOTOMETRY.

IN the fargone centuries, when the sun and the stars were looked upon as deities, and their priests were astronomers, who anxiously scanned their phases for signs of the future, not only the positions of the planets and stars were noted, but even their brightness. In the fascinating work by Professor Pritchard, entitled "Manometria Nova Oxoniensis: a Photometric Determination of the Magnitudes of all the Stars visible to the naked Eye from the Pole to Ten Degrees South of the Equator" (which should be carefully studied by the intending student of this branch of Photometry), the author says, in reference to a celestial globe constructed by Eudosius four centuries before the Christian Era: "There can be no doubt that some method was at the same time devised for the designation thereon of their [the stars] relative brightness. . . . But it is to Ptolemy, in his immortal work, the Almagest, that we are indebted for a record, not only of the celestial co-ordinates of the stars visible in his day (*cir.* A.D. 150) at Alexandria, but also for a catalogue of their relative brightness, such as he had himself probably received from Hipparchus and his predecessors more remote. It is a remarkable instance, among

many others, of the incisive intellect of the ancient Greeks that they adopted not only such an admirable nomenclature for stellar brightness, which has remained substantially unaltered to the present day, but one which even in its minuter sub-divisions has been but slightly improved by modern astronomers. It is still more remarkable that in this ancient and conventional nomenclature, they practically but unconsciously anticipated an important and fundamental law in Photometry, the first verbal expression of which was brought into prominence by Fechner at so recent a date as 1859. These ancient astronomers, as is well known, divided the brightness of the stars, conceived by them under the thought of 'magnitude,' into six classes." They also attempted to differentiate each "magnitude" into three divisions or thirds of a magnitude.

The first Photometer constructed for stellar purposes was that of Sir John Herschell, who, while at the Cape of Good Hope, devised an instrument which Professor Pritchard describes as consisting of "a pole, a prism, a small lens of short focus, a few strings, and a graduated tape. With these materials properly arranged, he could obtain, in the focus of the lens, a microscopic image of the moon, and this he could view in any direction, and at any measured distance from the eye; so that, being brought into the same line of sight as any particular star, he could alter the distance of the tiny image, until it and the star appeared to be equally bright."

About the same time Steinheil, of Munich, arranged a Photometer of different construction. It consisted, says Pritchard, of a small telescope with a divided object-glass, each of the halves of which was furnished with a reflecting

prism; so that, by means of suitable mechanism, the images of two stars might be viewed side by side in the telescope. The two halves of the object-glass were capable of motion in the axis of the telescope; so that the images of the two stars, when diffused into small discs, might be equalized in brightness, by placing the respective object-glasses at different measurable distances from the eye-piece. The results of this arrangement seemed to have been very satisfactory.

Zöllner devised a Photometer by using Arago's suggestion of the method of polarization. He used a comparison star formed artificially by a lamp, the light of which could be reduced by double refraction through a measurable quantity. Of this method Professor Pritchard says that the "unavoidable want of uniformity in the light of the lamp, and the impossibility of imitating exactly the appearance of an actual star, are fundamental difficulties in the use of this otherwise convenient and ingenious instrument."

Peirce, in his account of his photometric researches, 1872-5, in speaking of this instrument, says: "There is not any great difficulty in comparing two lights of different colours, and deciding which is the brighter. The difficulty lies chiefly in the fact that a change in the objective light produces less change in the sensation of blue than in those of red and green; so that the warmer coloured stars appear relatively brighter on fine clear nights. If we could keep an artificial star constant in colour, and could easily modify the colour in a known way, all difficulty in comparing stars of different colour could be overcome. But since this cannot be done, I should prefer, in constructing a Photometer, to leave the artificial star fixed in brightness, and only alter

the light of the real star." Peirce used a kerosene lamp to produce an artificial star. The light shone through a metallic chimney, and thence on to a disc perforated with pinholes, the longest and shortest diameters of which were as 10 to 2 (nearly). He does not, however, give an idea of the photometrical value of the lamp, or that portion exposed to the pinholes.

Perhaps few observers have paid more attention to this subject than Professor Pickering, of Harvard College, whose researches have been of the most refined character. In the years 1877-9, this authority employed no less than four different forms of Photometers, which were all of a polariscopic nature. An elaborate account of these is given in Vol. XIV. of the "Annals of the Astronomical Observatory of the Harvard College." The Meridian Photometer, as one form was termed, was a telescope placed horizontally at right angles to the meridian. In it was placed two object-glasses, with their axes slightly inclined to each other. Each object-glass was 4 centimètres in diameter, and was armed with an adjustable reflecting prism. By these means images of Polaris and of any star near the meridian could be formed in the common focal plane of the two object-glasses after having passed through a suitable combination of double refracting prisms. The polarized images of the two stars were then equalized, and their brightness determined. Professor Pickering also applied the principle of the polarization of light to the photometry of double stars, with success; but, says Professor Pritchard, the question of the equalization of some of the more vividly coloured stars still remains of doubtful solution, and, it may be, is beyond the reach of physical considerations alone.

Knobel uses a system of obscuration. By reducing the silvered reflecting surface of the mirrors of a Newtonian telescope, he extinguishes the light of the stars well visible to the naked eye, and thus compares their value.

The Wedge Photometer is constructed on the principle that light in passing through a transparent homogeneous medium loses an amount of intensity depending on the thickness of the latter. The Wedge Photometer employed at Oxford is described by Professor Pritchard as follows:— This is a wedge of very nearly neutral tinted glass, 6½ inches long, 1 inch broad, and 0·145 inch thick, tapering off to 0·02 inch. Cemented to it is a similar wedge of white glass, placed the reverse way; the whole forming a rectangular prism. This glass prism or "wedge," as it is called, is enclosed in a brass cellular rim with bevelled edges, one of which is divided into tenths of an inch; the divisions being distinct and white for visibility at night. It slides in a groove on the brass cap of any telescope, close to the achromatic eye lens, and is thus placed between the eye of the observer and the telescope. In the focus of the eye lens is a diaphragm pierced with a number of small holes, which vary from 1-100th of an inch to ¼ inch in diameter, and in which small circular hole the telescopic image of a star is carefully placed, and there viewed through the wedge. Further, the eye of the observer is directed along the axis of the lens of the telescope by means of an external eye-hole, placed closed to the wedge, and varying from 1-12th of an inch to ¼ inch. This direction of vision is very important. A fiducial mark is drawn on the brass cap of the eye-piece, so that the position of the wedge can be distinctly denoted

and recorded *when the image of the star is just extinguished by the wedge*. Usually the position of the wedge, when the light of the star is just extinguished, is observed five times, and the mean of all the five readings is called the *wedge reading*. The extinction of a second star is then observed in a similar manner, and the difference between the two wedge readings is called the "wedge interval." This wedge interval is obviously a measure of the difference of the thickness of the neutral tinted glass of the wedge at the points where the two stars are respectively extinguished; and this "wedge interval" is also a direct measure of the difference of the "magnitudes" of the two stars whose lights are respectively just extinguished at the two points of the wedge.

The remarks of Professor Pritchard regarding the "unavoidable want of uniformity in the light of the lamp, and the impossibility of imitating exactly the appearance of an actual star, are fundamental difficulties in the use of Zöllner's system," and again, in reference to Professor Pickering's proposals, "the question of the equalization of some of the more vividly coloured stars still remains of doubtful solution, and, it may be, is beyond the reach of physical considerations alone," have induced the Author to reconsider these points in connection with a form of Stellar Photometer which he has recently constructed. The artificial star used by the Author is obtained by a modification of Methven's screened Argand standard. For practical purposes it may be safely assumed that the area of the luminous flame opposed to the slot in this screen is of equal intensity in all parts. If, then, the area is reduced, the intensity of the light emitted from the slot will be reduced proportionately; and thus is obtained a series of minute apertures perfectly spherical in

contour, representing, when placed at a distance, an exact imitation of a star of *known illuminating power in terms of a standard "candle."* For comparison with stars of different colours, the colour of the gas-flame is modified by placing

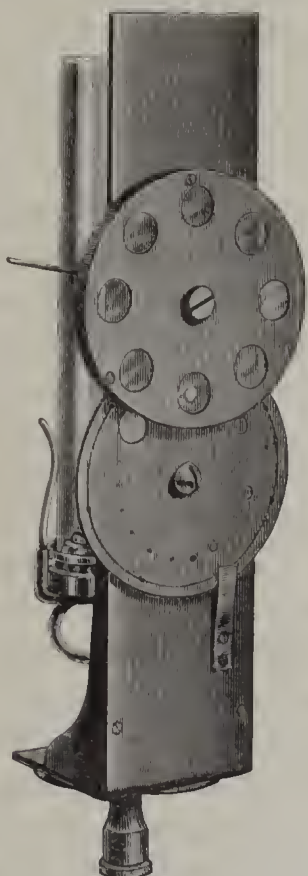

FIG. 23.—CHROMATIC STANDARD FOR STELLAR PHOTOMETRY.

in front of it coloured glasses of suitable tints. The reduction in the intensity of the light thus caused is ascertained on the ordinary Photometer with the full aperture of the slot, which is ordinarily equal to 2 candles. The use of the Author's

improved Leeson disc, as explained on p. 83, renders the determination of the photometrical value of coloured lights a matter of certainty. A scale is then easily prepared of artificial stars of varying colour and size, and of absolutely *known and constant intensity* in terms of the English legal unit of light. A silver plate is used for the screen; and in this the apertures are punctured. These are carefully measured under the microscope, and their areas calculated. In this way it is not difficult to obtain a standard star of no more than $\frac{1}{10000}$th of a candle, which can be still further reduced by the interposition of a coloured glass, the absorbing power of which has been previously ascertained as already described. The table on the next page shows the value of a series of standard artificial stars thus prepared.

The Photometer employed by the Author consists of an optically plane silver-on-glass mirror mounted in front of the object-glass of the telescope (p. 172). By means of directing rods and rackwork adjustment, the position of the mirror can be directed from the eye-end of the telescope. When observing, the instrument is placed at a convenient distance from the standard artificial star (say) 100 feet, which position may be taken as a convenient one for general adoption; and the artificial star brought into the centre of the field of view, the telescope being horizontal. The mirror is then placed so that one-half of the object-glass is obscured by it; the light from the artificial star being thus correspondingly reduced, as a portion of a lens will act as a whole lens—the difference being merely one of loss of light. The mirror is then inclined and placed at such an angle that the real star, preferably in the zenith, is reflected from the polished silver surface until it is seen in the telescope, the focus of which

## STELLAR CHROMATIC PHOTOMETRY.

TABLE *of Values of Standard of Light with various Colours.*

| No. of Aperture in Plate. | Diameter of Aperture. Inch. | Area of Aperture. Inch. | Photometrical Values, in terms of an average Sperm Candle. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Aperture Uncov'd. | Aperture covered with Glass coloured— | | | | | | |
| | | | | Red. | Orange. | Yellow. | Green. | Lt. Blue. | Dk. Blue. | Purple. |
| 1 | 0·490 | 0·125664 | 1·0000 | 0·066666 | 0·137000 | 0·357000 | 0·166000 | 0·166000 | 0·062500 | 0·045500 |
| 2 | 0·275 | 0·059398 | 0·5000 | 0·033333 | 0·068500 | 0·178500 | 0·083000 | 0·083000 | 0·031250 | 0·022750 |
| 3 | 0·115 | 0·010387 | 0·0875 | 0·005830 | 0·011990 | 0·031240 | 0·014520 | 0·014520 | 0·005469 | 0·003980 |
| 4 | 0·085 | 0·005674 | 0·0477 | 0·003180 | 0·006540 | 0·017030 | 0·007910 | 0·007910 | 0 002980 | 0·002170 |
| 5 | 0·058 | 0·002642 | 0·0222 | 0·001480 | 0·003014 | 0·007920 | 0 003680 | 0·003680 | 0 001390 | 0·001010 |
| 6 | 0·044 | 0·001520 | 0·0128 | 0·000853 | 0·001754 | 0·004570 | 0·002125 | 0·002125 | 0·000800 | 0·000582 |
| 7 | 0·033 | 0·000855 | 0·0072 | 0·000480 | 0·000986 | 0·002570 | 0·001195 | 0·001195 | 0·000450 | 0·000327 |
| 8 | 0·023 | 0·000415 | 0·0035 | 0·000233 | 0·000479 | 0·001250 | 0·000581 | 0·000581 | 0·000219 | 0·000159 |
| 9 | 0·018 | 0·000254 | 0·0021 | 0·000140 | 0·000287 | 0·000749 | 0·000349 | 0·000349 | 0·000131 | 0·000095 |
| 10 | 0·013 | 0·000132 | 0·0011 | 0·000073 | 0·000151 | 0·000393 | 0·000183 | 0·000183 | 0·000069 | 0·000050 |
| 11 | 0·010 | 0·000078 | 0·0007 | 0·000047 | 0·000096 | 0·000250 | 0·000116 | 0·000116 | 0·000044 | 0·000032 |
| 12 | 0·008 | 0·000050 | 0·0004 | 0·000027 | 0·000055 | 0·000143 | 0·000066 | 0·000066 | 0·000025 | 0·000018 |

The value of the apertures Nos. 3 to 12 are calculated from the area of the second aperture, which gives a light equal to ½ candle, as determined by direct experiment.

The results are uncorrected for diffraction.

is altered for the purpose. When the real star is thus found, the eye-piece is racked out until, as in Steinheil's method, the two stars—the real and artificial—are seen as equal-sized discs. The comparison of luminosity is then made by adjusting the height of the mirror, so as to expose

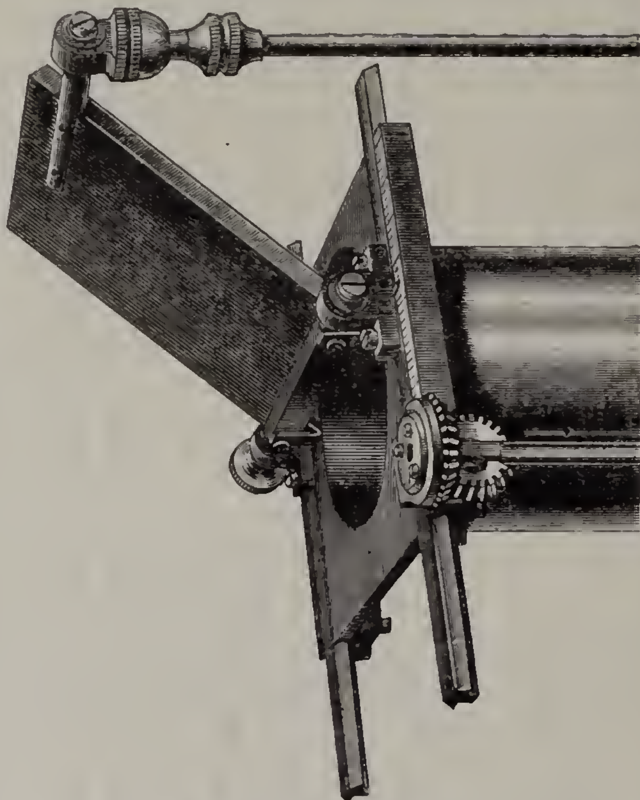

FIG. 24.—MIRROR IN POSITION FOR STELLAR PHOTOMETRY.

the greater area of the object-glass to the weaker light of the two, until they appear of equal brilliancy in the telescope. A scale on the framework holding the mirror is then read, and the areas exposed to the two stars respectively obtained

by reference to a table (p. 174) previously prepared showing the relative areas exposed when the mirror is in various positions. The relative intensity of the two stars having been thus ascertained, and the photometrical value of the artificial star being known, all the elements are found for computing the intensity of the light of the real star. Fig. 24 is an illustration of the instrument.

The table on p. 174, showing the percentage area of the object-glass exposed to the mirror, and left clear to the real or artificial star as the case may be, with the foregoing table of the intensity of a series of artificial stars, will assist the reader in comprehending the method now proposed.

When the eye-piece is racked out to diffuse the focus of the stars into small discs, it will be noticed that the form of the disc is not maintained, in consequence of the mirror cutting off a portion of each. But if an artificial star of nearly equal intensity is used, no difficulty is observed in judging of the value of the two semi-spherical discs, as it is very easy to set the eye-piece at such a point that they are of equal size. The greatest inconvenience arises from the difficulty of setting the mirror at the required angle to reflect the required star into the field of view. If, however, a small telescope or "finder" is fitted in such a manner that its deviation from the vertical is shown on a scale divided into degrees, it becomes an easy matter to adjust the mirror to the required angle, more especially so as a low power eye-piece will be found most suitable for these observations. A further refinement would be to provide the mirror with an equatorial mount fitted with clockwork adjustment, when the mirror would keep the star in the field for far longer periods than are required for an observation,

## Table for Computing Observations by Silvered Mirror.

When the bottom of the mirror is at $x$ division from the upper circumference of the lens or from the centre, the aperture open to the mirror, and that portion unscreened, will be as follows:—Area of lens, $3\frac{1}{4}$ inches diameter = 8·294 inches.

| Divisions on Side Scale. | | Aperture Exposed to Mirror. | | Aperture Freely Exposed or Unscreened. | |
|---|---|---|---|---|---|
| From Top. | From Centre. | Area in Inches. | Area Per Cent. of Total. | Area in Inches. | Area Per Cent. of Total. |
| Divisions are in 01 Inch. | | | | | |
| 0 | 17 | 0·000 | 0 | 8·294 | 100·0 |
| 1 | 16 | 0 008 | 0·1 | 8·286 | 99·9 |
| 2 | 15 | 0·105 | 1·3 | 8·189 | 98·7 |
| 3 | 14 | 0·252 | 3·0 | 8·042 | 97·0 |
| 4 | 13 | 0·434 | 5·2 | 7·860 | 94·8 |
| 5 | 12 | 0·641 | 7·7 | 7·653 | 92·3 |
| 6 | 11 | 0·871 | 10·5 | 7·423 | 89·5 |
| 7 | 10 | 1·119 | 13·5 | 7·175 | 86·5 |
| 8 | 9 | 1·384 | 16·7 | 6·910 | 83·3 |
| 9 | 8 | 1·661 | 20·0 | 6·633 | 80·0 |
| 10 | 7 | 1·950 | 23·5 | 6·344 | 76·5 |
| 11 | 6 | 2·247 | 27·1 | 6·047 | 72·9 |
| 12 | 5 | 2·552 | 30·7 | 5·742 | 69 3 |
| 13 | 4 | 2·864 | 34·5 | 5·430 | 65·5 |
| 14 | 3 | 3·180 | 38 3 | 5·114 | 61·7 |
| 15 | 2 | 3·501 | 42·2 | 4·793 | 57·8 |
| 16 | 1 | 3·823 | 46·1 | 4·471 | 53·9 |
| 17 | 0 | 4·147 | 50·0 | 4·147 | 50·0 |
| 18 | 1 | 4·471 | 53·9 | 3·823 | 46·1 |
| 19 | 2 | 4 793 | 57·8 | 3·501 | 42·2 |
| 20 | 3 | 5·114 | 61·7 | 3 180 | 38·3 |
| 21 | 4 | 5·430 | 65·5 | 2·864 | 34·5 |
| 22 | 5 | 5·742 | 69·3 | 2·552 | 30·7 |
| 23 | 6 | 6·047 | 72·9 | 2·247 | 27·1 |
| 24 | 7 | 6·344 | 76·5 | 1·950 | 23·5 |
| 25 | 8 | 6·633 | 80·0 | 1·661 | 20·0 |
| 26 | 9 | 6·910 | 83 3 | 1·384 | 16·7 |
| 27 | 10 | 7·175 | 86·5 | 1·119 | 13·5 |
| 28 | 11 | 7·423 | 89·5 | 0·871 | 10·5 |
| 29 | 12 | 7·653 | 92·3 | 0·641 | 7·7 |
| 30 | 13 | 7·860 | 94·8 | 0·434 | 5·2 |
| 31 | 14 | 8 042 | 97·0 | 0·252 | 3·0 |
| 32 | 15 | 8·189 | 98·7 | 0 105 | 1·3 |
| 33 | 16 | 8·286 | 99·9 | 0·008 | 0·1 |
| 34 | 17 | 8·294 | 100·0 | 0·000 | 0·0 |

which, indeed, is made with the greatest facility and readiness. For the purpose of correcting the observations for error due to absorption of light by the mirror, the best plan is to make several trials with the telescope pointed first to the artificial star and then to the real star, when the mean variations will afford a constant for all future observations so long as the reflecting surface of the mirror remains untarnished. The Author is engaged upon a series of observations which he hopes to publish shortly.

The following extracts from the "Monthly Notices of the Royal Astronomical Society," Vol. XVI., 1856, p. 206, of a paper by Professor Argelander, on "Suggestions respecting a Method for Determining the Brightness of the Minor Planets," are so full of useful information on the general subject that they will well repay careful perusal. After some preliminary remarks on the importance of observations on the brightness of the minor planets, he says:

"1. Since we have reason to suppose that all the minor planets revolving between Mars and Jupiter have had a common origin, we may conclude that they are all characterized by the same, or at least nearly the same colour of surface. Hence the determination of their relative brightness would serve to indicate their relative magnitudes; and consequently we might arrive at a knowledge of their absolute magnitudes, if we should once be in a position to determine the approximate diameter of one of them. It is not impossible that in the course of time we may be enabled to accomplish this object. No reliance can be placed upon any results of this nature which have been hitherto obtained by observers; or, at all events, they can only be considered as affording in each instance a superior limit of the true

measure. It cannot be doubted, however, that the immense telescopes, which are now directed towards the heavens in different parts of the world, will enable the observer under favourable circumstances, to arrive at trustworthy results in relation to this object. Hence the determination of the mean brightness, and the comparison of the values of that element for the different planets, must form one of the principal objects of the research.

"2. It is well known that observers have suspected variations in the brightness of several of the minor planets, which seemed to indicate a rotation on an axis. The author himself had announced an observation of this kind which appeared in No. 325 of the *Astronomische Nachrichten.* Such a conclusion, however, is very doubtful; the influence of atmospheric circumstances being very deceptive. The atmosphere, especially in our latitudes, is scarcely ever free from vapours. Even during apparently the most serene sky, the heavens are here and there disturbed by very minute vapours, the presence of which is recognized by the fact that very faint stars suddenly vanish altogether and soon reappear; while others in their vicinity, which were easily perceived, now cease to be visible. It is manifest that such disturbing causes must exercise an influence upon the brightness of stars which do not vanish altogether. In observations with an illuminated field of view, we have to encounter another difficulty arising from the circumstance of the illumination being not always the same. This must be adapted to the brightness of the object to be observed. The degree of faintness of the field affords now, indeed, an estimate of the brightness of the star; but a very imperfect one, since the eye very soon accustoms itself to a faint

illumination, and imagines it to be more intense than it really is. It is only by direct and repeated comparisons of two stars that we can hope to arrive at anything approaching trustworthy results. In this way, however, we may succeed in detecting real variations of light in the small planets. Should these arise from the existence of irregularities on the surfaces of the planets, combined with a movement of rotation, they ought, as a necessary consequence, to return at regular intervals of time. It is possible, however, that they may be due to other causes. It seems, indeed, very probable that the space between the planets of our system is not absolutely empty; but is pervaded more or less by a fluid substance, or by small bodies."

Amongst other difficulties, Professor Argelander points out the different impression produced upon the eye by variously coloured lights, and by the particular kind of telescope employed in the observation, and says that the proposed method must solve all those ambiguities. The one recommended by him is as follows :—

"1. Select a series of fixed stars of different magnitudes which may serve as points of reference for comparison of brightness. Such stars can only be found in the region of the Pole—say, between δ Ursæ Minoris and 24 Cephei (Hev).

"2. A number of these stars, including every degree of brightness, must be carefully compared, and their relative brightness determined by repeated observations. The author alludes to the method which has been employed for effecting this object by comparisons of equal brightness. He remarks that, according to his own experience, one may judge with equal precision respecting minute gradations of light; and that results equally worthy of confidence will

be obtained if the observer should compare the star whose brightness is to be determined with two other stars, one of which is a little brighter, and the other a little fainter. He accordingly proposed the method which he employed in the observation of variable stars. Designating the faintest of the stars by 0, the next brighter by 1, 2, 3, &c., a scale of comparison will thereby be formed which will serve to ascertain the relative brightness of the small planets.

"3. It would not be advisable to compare the planet directly with the stars of the scale which approach it in brightness; but with two stars in its vicinity, one being a little brighter and the other a little fainter than itself. It is not necessary that these stars should be visible in the field of the telescope at the same time as the planet. It is even desirable to select them at some distance from the planet preceding or following the latter, so as to be enabled to employ the same stars of comparison for several days. By this means the observer is enabled to recognize with greater facility the existence of slight periodic variations in the brightness of the planet. But the principal advantage he derives from the process consists in the elimination of the effects of any irregularities in the condition of the atmosphere in the region of that planet and that of the scale. The stars which have been directly compared with the planet must now be compared with as many stars of the scale as possible.

"4. This process will be very difficult if the observer have at his disposal only one telescope, which he turns alternately upon the scale and the region of the planet; and the time which elapses will be too long for the impression which the brightness of the first star has left in the eye to remain undiminished until the observer is enabled to consider the

second star. The observer must abandon the use of very large telescopes in researches of this kind, and must content himself with instruments of moderate power. Telescopes of 48, and even 42 lines aperture, will amply suffice for accurate comparisons of stars to the tenth magnitude. They possess at the same time the advantage of being applicable to observations of the brightest of the small planets in all stages of brightness, which is not the case with respect to large refractors. In these the stars of the sixth and seventh magnitudes, and even the brightest stars of the eighth magnitude, have so much light that it is impossible to estimate the brightness with any degree of certainty.

" The observer must now direct one of the telescopes to the scale; and the other to the region of the planet. The two instruments must be so placed that the eye-pieces shall be near to each other; and the eye in a few seconds can pass from the one to the other. It is a matter of importance that both telescopes should have the same optical power."

It does not appear that this method has been extensively followed; and the fact that neither Professor Pritchard nor Professor Pickering has adopted it does not speak well for it in the estimation of those distinguished astronomers. The wedge system adopted by the former is undoubtedly the most simple and convenient to use, and appears to have found most favour. The direct system proposed by the Author has yet to be thoroughly tried. The fact that the standard is a constant one, and easily reproduced to an indefinite extent, is in its favour; and it has the further advantage that its colour may be varied to any tint required—the photometrical co-efficient of such variation being easily found, and remaining constant for all subsequent experiments.

By this system a method is provided for stating the values of the various "magnitudes" in terms of the English unit of light—the candle—and this applies whether the comparisons are made by the methods of direct reflection from a silvered mirror (as now proposed), by the wedge method of obscuration, or by any one of the various polariscopic methods suggested by Professor Pickering and others.

# APPENDIX.

## METROPOLIS GAS.

### NOTIFICATION OF THE GAS REFEREES FOR THE SUMMER, 1889.

*Office of the Metropolitan Gas Referees,*
17, *Buckingham Street, Adelphi, W.C.*
*March*, 1889.

Whereas the undersigned have been appointed "Gas Referees" under the City of London Gas Act, 1868; The Gaslight and Coke Company's Act, 1876; the South Metropolitan Gaslight and Coke Company's Act, 1869; the South Metropolitan Gaslight and Coke Company's Act, 1876; the Commercial Gas Act, 1875; and The Gaslight and Coke and other Gas Companies' Acts Amendment Act, 1880.

And whereas it is the duty of the said Gas Referees, under the same and other Acts of Parliament, among other things, to prescribe and certify what testing-places shall be provided by each Gas Company; and to prescribe the mode to be adopted for testing and recording the illuminating power, purity, and pressure of the gas, and the number of the times of testing; and to prescribe and certify the maximum amount of impurity in each form with which the gas shall be allowed to be charged:

Now, therefore, in compliance with the provisions of the said Acts, the said Gas Referees do hereby prescribe and certify as follows; that is to say,

As to the
Testing-Places.

The testing-places shall, for the present, be as follows:—

*For The Gaslight and Coke Company—*

1. At No. 3, Jewry Street, Aldgate.
2. At No. 10, Kinghorn Street, Cloth Fair.

3. At No. 1, Dorset Buildings, Dorset Street, Salisbury Square.
4. At No. 21, Millbank Street.
5. At No. 123, Ladbroke Grove, Notting Hill.
6. At No. 11, Devon's Road, Bromley, Bow.
7. At No. 1, Carlyle Square, Chelsea.
8. At No. 170, Camden Street, Camden Town.
9. At No. 14*a*, Graham Road, Dalston.
10. At No. 47, Kingsland Road.
11. At the Offices of the London County Council, Spring Gardens.
12. At No. 4, Grove Gardens, Regent's Park.
13. At No. 116, Lambeth Road.
14. At No 121, Hornsey Road, Holloway.

*For the Commercial Gas Company*—

1. At No. 6, Wellclose Square, St. George's, E.
2. At No. 24, Parnell Road, Old Ford.

*For the South Metropolitan Company*—

1. At No. 104, Hill Street, Peckham.
2. At No. 87, Bedford Road, Clapham Road.
3. At No. 1, Stoney Lane, Tooley Street.
4. At No. 180, Lewisham Road, Lewisham.
5. At No. 99, Blackfriars Road.
6. At No. 211, Burrage Road, Plumstead.

As to the

Times and Mode of Testing for Illuminating Power.

The testings for illuminating power shall be three in number daily, to be taken at intervals of not less than one hour. But if one of these testings assigns to the gas an illuminating power differing by more than one candle from the illuminating power assigned to the gas by another testing, or if the average of three testings of illuminating power fall below the prescribed illuminating power, a fourth testing shall be made after a further interval of one hour.

The Photometers to be used in the testing-places shall be the improved forms of the Bunsen Photometer, prescribed and certified by the Referees.

The burner attached to each Photometer shall be a standard burner corresponding to that which has been deposited with the Warden of the Standards in accordance with Section 37 of The Gaslight and Coke

Company's Act, 1876. A description of the standard burners to be used for testing common gas and cannel gas respectively is given in Appendix A.

The gas in the Photometer is to be kept burning for at least fifteen minutes before any testing is made.

The disc used in the Photometer shall be either the improved Leeson or the Bunsen disc. When a disc is not in use, it should be covered to protect it from dust; and if a disc is in any way marked or soiled, a clean disc is to be substituted.

A clean chimney is to be placed on the burner before each testing.

The candles shall be such as are described in Section 25 of the Metropolis Gas Act of 1860—namely, sperm candles of six to the pound, each burning 120 grains an hour. Two of the candles shall be used together. The three testings made on one day shall be made with three different pairs of candles.

Each testing shall consist of ten observations of the Photometer, made at intervals of one minute. When five observations have been made, the disc and mirrors are to be reversed by being turned round through half a circle. The average of each set of ten observations is to be taken as representing the illuminating power for that testing.

The rate of burning of the gas in each burner shall be 5 cubic feet per hour—a rate of consumption which is shown by the long hand of the meter making exactly one revolution per minute for several minutes consecutively.

The candles are to be lighted at least ten minutes before the beginning of each testing, so as to have attained their normal rate of burning. The Gas Examiner may ascertain whether the candles are burning at nearly the normal rate by placing a four-grain weight in the candle-pan when the balance turns, and observing whether the balance turns again in one minute. Before each testing the two candles are to be so placed that the plane of the curvature of one wick shall be perpendicular to the plane of the curvature of the other wick.

Before and after making each testing, the Gas Examiner shall counterpoise the candles; and if the rate of consumption per candle shall not have exceeded 126 grains per hour, or fallen short of 114 grains per hour, he shall make, and record in a book to be kept for the purpose, the calculations requisite to neutralize the effects of this difference. If the rate of consumption shall have varied from the prescribed

rate beyond the above-named limits, or if the Gas Examiner should observe during the testing that the candles are burning irregularly, or that their flames are not exactly between the two plumb-lines which mark their true position, the testing is to be rejected, and a fresh testing made.

Instead of weighing the candles, the Gas Examiner may observe the time in which 40 grains are burnt. This must not exceed 10·5, or fall short of 9·5 minutes.

The Gas Examiner shall, at least once a week, compare the meter-clock with the standard clock in each testing-place.

At the time of each testing the Gas Examiner shall observe and record the temperature of the gas, as shown by the thermometer attached to the meter, and also the height of the barometer. The volumes of the gas operated upon during the testings may be corrected from these data (the standard of comparison being, for the barometer, 30 inches; and for the thermometer, 60°) by means of the table given in Appendix C. Suppose, for example, the thermometer stands at 54°, and the barometer at 30·3 inches: multiply the quantity of gas consumed by the corresponding *tabular number*, the product will be the corrected volume of the gas—*i.e.*, the volume the gas would have occupied when measured over water at the standard temperature and pressure. Thus:

Volume of gas consumed . . . . . . . . . . 5 cubic feet.
Tabular number for barometer and thermometer. . 1·025

Then $1{\cdot}025 \times 5 = 5{\cdot}125$, the corrected volume.

Instead of thus correcting the volume of gas consumed, the same object may be attained by dividing the observed illuminating power by the tabular number, or in the manner described on page 191.

The Gas Examiner shall enter in his book the particulars of every testing of illuminating power made by him at the testing-places, immediately after such testing; and in the case of any testing which he rejects, he shall also state the cause of rejection. A form in which to record his observations and calculations is given in Appendix D. No testing is to be rejected on the ground that the result seems improbable.

The calculations for working out the corrections, &c., for the illuminating power of the gas proceed in the following manner:—Add the observations together, and divide the sum by 10 to get the average. Then, as two candles are used, multiply by 2, to get the illuminating power of the gas if tried against one candle. Then, as the standard rate

of consumption of the candles—viz., 120 grains—is to the average number of grains consumed by each per hour, so is the above-obtained number to the actual illuminating power. Finally, make the correction for temperature and pressure, by dividing the illuminating power by the tabular number. For example (taking the tabular number as 1·025) :—

*Observations*—

| | | |
|---|---|---|
| 1st | minute— | 7·8 |
| 2nd | ,, | 7·8 |
| 3rd | ,, | 8·1 |
| 4th | ,, | 8·2 |
| 5th | ,, | 8·3 |
| 6th | ,, | 8·5 |
| 7th | ,, | 8·6 |
| 8th | ,, | 8·4 |
| 9th | ,, | 8·3 |
| 10th | ,, | 8·6 |

10)82·6

Consumption of the 2 candles in 10 minutes =41 grains.
3
———
123=Consumption of 1 candle per hour.

Average, by 2 candles - - = 8·26
2
———
Average, by 1 candle - - = 16·52
Consumption by one candle per hour - - - } 123 grains.
———
4956
3304
1652
———
Standard consumption 120)203196
———
Correction for temp. & pres. 1025)16933(16·5=corrected illum. power in candles.
1025
———
6683
6150
———
5330
———

The foregoing calculation can be shortened as follows, which is the form prescribed in Appendix D :—

*Observations*—

| | | |
|---|---|---|
| 1st | minute— | 7·8 |
| 2nd | ,, | 7·8 |
| 3rd | ,, | 8·1 |
| 4th | ,, | 8·2 |
| 5th | ,, | 8·3 |
| 6th | ,, | 8·5 |
| 7th | ,, | 8·6 |
| 8th | ,, | 8·4 |
| 9th | ,, | 8·3 |
| 10th | ,, | 8·6 |

———
82·6
Consumption by two candles in 10 minutes - - } 41 grains.
———
826
3304
———
2)33866
———
Tabular number - - - 1025)16933(16·5=corrected illum. power in candles.
1025
———
6683
6150
———
5330
———

As to the

TIMES AND MODE OF TESTING FOR PURITY.

The testings for purity shall extend over twenty hours of each day, and shall be made upon 10 cubic feet of gas, which shall be tested successively for each of the following impurities.

I.—*Sulphuretted Hydrogen.*

The gas shall be passed as it leaves the service-pipe through an apparatus in which are suspended slips of bibulous paper, impregnated with basic acetate of lead.

The test-paper from which these slips are cut is to be prepared from time to time by moistening sheets of bibulous paper with a solution of one part of sugar of lead in eight or nine parts of water, and holding each sheet while still damp over the surface of a strong solution of ammonia for a few moments. As the paper dries all free ammonia escapes.

If any discoloration of the slip of test-paper is found to have taken place, this is to be held conclusive as to the presence of sulphuretted hydrogen in the gas. Fresh test-slips are to be placed in the apparatus every day.

In the event of any impurity being discovered, one of the test-slips shall be placed in a stoppered bottle, and kept in the dark at the testing-place. The remaining slips shall be forwarded with the daily report (Appendix E).

II.—*Ammonia.*

The gas which has been tested for sulphuretted hydrogen shall pass next through an apparatus consisting of a glass cylinder filled with glass beads, which have been moistened with a measured quantity of standard sulphuric acid. A set of burettes, properly graduated, is provided.

The maximum amount of ammonia allowed is 4 grains per 100 cubic feet of gas; and the testings shall be made so as to show the exact amount of ammonia in the gas.

Two test-solutions are to be used—one consisting of dilute sulphuric acid of such strength that 25 measures (septems) will neutralize 1 grain of ammonia; the other a weak solution of ammonia, 100 measures of which contain 1 grain of ammonia.

The correctness of the result to be obtained depends upon the fulfilment of two conditions:—

1. The preparation of test-solutions having the proper strength.
2. The accurate performance of the operation of testing.

To prepare the test-solutions, the following processes may be used by the Gas Examiner.

Measure a gallon of distilled water into a clean earthenware jar, or

other suitable vessel. Add to this 94 septems of pure concentrated sulphuric acid, and mix thoroughly. Take exactly 50 septems of the liquid and precipitate it with barium chloride in the manner prescribed for the sulphur test. The weight of barium sulphate which 50 septems of the test-acid should yield is 13·8 grains. The weight obtained with the dilute acid prepared as above would be somewhat greater, unless the sulphuric acid used had a specific gravity below 1·84.

Add now to the diluted acid a measured quantity of water, which is to be found by subtracting 13·8 from the weight of barium sulphate obtained in the experiment, and multiplying the difference by 726. The resulting number is the number of septems of water to be added.

If these operations have been accurately performed, a second precipitation and weighing of the barium sulphate obtainable from 50 septems of the test-acid will give nearly the correct number of 13·8 grains. If the weight exceeds 13·9 grains, or falls below 13·7 grains, more water or sulphuric acid must be added, and fresh trials made, until the weight falls within these limits. The test-acid thus prepared should be transferred at once to stoppered bottles which have been well drained and are duly labelled.

To prepare the standard solution of ammonia, measure out as before a gallon of distilled water, and mix with it 50 septems of strong solution of ammonia (sp. gr. 0·88). Try whether 100 septems of the test-alkali thus prepared will neutralize 25 of the test-acid, proceeding according to the directions given subsequently as to the mode of testing. If the acid is just neutralized by the last few drops, the test-alkali is of the required strength. But if not, small additional quantities of water, or of strong ammonia solution, must be added, and fresh trials made, until the proper strength has been attained. The bottles in which the solution is stored should be filled nearly full and well stoppered.

The mode of testing is as follows:—Take 50 septems of the test-acid (which is greatly in excess of any quantity of ammonia likely to be found in the gas), and pour it into the glass cylinder, so as to well wet the whole interior surface, and also the glass beads. Connect one terminal tube of the cylinder with the gas supply, and the other with the meter, and make the gas pass at the rate of about half a cubic foot per hour. Any ammonia that is in the gas will be arrested by the sulphuric acid, and a portion of the acid (varying with the quantity of ammonia in the gas)

will be neutralized thereby. At the end of each period of testing, wash out the glass cylinder and its contents with distilled water, and collect the washings in a glass vessel. Transfer one-half of this liquid to a separate glass vessel, and add a quantity of a neutral solution of hæmatoxylin or litmus just sufficient to colour the liquid. Then pour into the burette 100 septems of the test-alkali, and gradually drop this solution into the measured quantity of the washings collected, stirring constantly. As soon as the colour changes (indicating that the whole of the sulphuric acid has been neutralized), read off the quantity of liquid remaining in the burette. To find the number of grains of ammonia in 100 cubic feet of the gas, multiply by 2 the number of septems of test-alkali remaining in the burette, and move the decimal point one place to the left.

The remaining half of the liquid is to be preserved in a bottle duly labelled for a week.

III.—*Sulphur Compounds other than Sulphuretted Hydrogen.*

The gas which has been tested for sulphuretted hydrogen and ammonia shall pass next through a meter, by means of which the rate of flow can be adjusted to half a cubic foot per hour, and which is provided with a self-acting movement for shutting off the gas when 10 cubic feet have passed.

The testing shall be made in a room where no gas is burnt other than that which is being tested for sulphur and ammonia.

The apparatus to be employed is represented below by a diagram, and is of the following description :—The gas is burnt in a small Bunsen burner with steatite top, which is mounted on a short cylindrical stand, perforated with holes for the admission of air, and having on its upper surface a deep circular channel to receive the wide end of a glass trumpet-tube. On the top of the stand, between the narrow stem of the burner and the surrounding glass trumpet-tube, are to be placed pieces of commercial sesqui-carbonate of ammonia weighing in all about 2 ounces.

The products both of the combustion of the gas and of the gradual volatilization of the ammonia salt go upwards through the trumpet-tube into a vertical glass cylinder, packed with balls of glass, to break up the current and promote condensation. From the top of the cylinder there proceeds a long glass pipe or chimney, serving to effect some further

condensation, as well as to regulate the draught, and afford an exit for the uncondensable gases. In the bottom of the cylinder is fixed a small glass tube, through which the liquid (formed during the testing) drops into a beaker placed beneath.

The following cautions are to be observed in selecting and setting up the apparatus :—

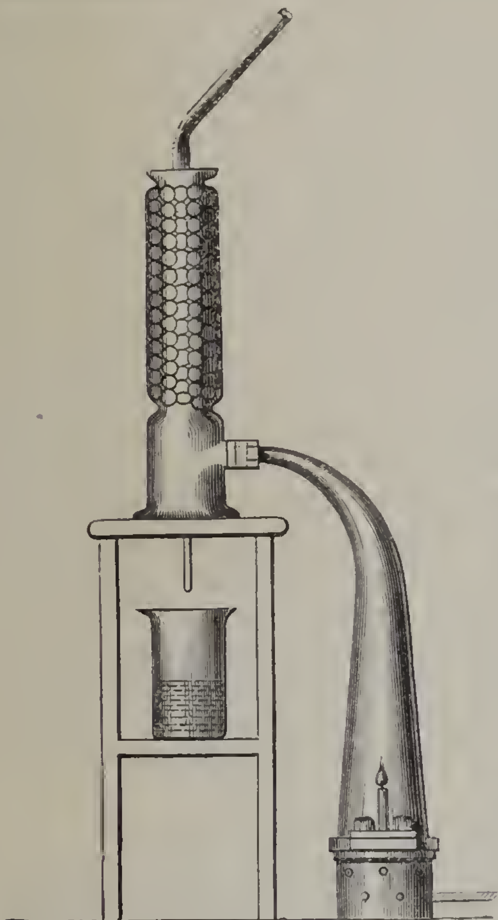

Fig. 25.—Apparatus for Testing for Sulphur Compounds.

See that the inlet-pipe fits gas-tight into the burner, and that the holes in the circular stand are clear. If the burner gives a luminous flame, remove the top piece, and having hammered down gently the nozzle of soft metal, perforate it afresh, making as small a hole as will give passage to half a cubic foot of gas per hour, at a convenient pressure.

See that the tubulure of the condenser has an internal diameter of not less than $\frac{3}{4}$ inch ; and that its outside is smooth and of the same size as the small end of the trumpet-tube.

See that the short piece of india-rubber pipe fits tightly both to the trumpet-tube and to the tubulure of the condenser.

The small tube at the bottom of the condenser should have its lower end contracted, so that when in use it may be closed by a drop of water.

The india-rubber pipe at the lower end of the chimney tube should fit into or over, and not simply rest upon, the mouth of the condenser; and the upper extremity of this tube may with advantage be given a downward curvature.

At the end of each period of testing, the cylinder and trumpet-tube are to be well washed out with distilled water. Fresh pieces of sesquicarbonate of ammonia are to be used each day.

The Gas Examiner shall then proceed as follows :—

The liquid in the beaker and the water used in washing out the

apparatus shall be put into the same vessel, well mixed, and measured. One-half of the liquid so obtained is to be set aside, and preserved for a week, properly labelled, in case it should be desirable to verify the correctness of the testing.

The remaining half of the liquid is to be put into a flask, or beaker covered with a large watch glass, treated with hydrochloric acid sufficient in quantity to leave an excess of acid in the solution, and then raised to the boiling-point. An excess of a solution of barium chloride is now to be added, and the boiling continued for five minutes. The vessel and its contents are to be allowed to stand till the barium sulphate settles at the bottom of the vessel, after which the clear liquid is to be as far as possible poured off through a paper filter. The remaining liquid and barium sulphate are then to be poured on to the filter; and the latter well washed with hot distilled water. (In order to ascertain whether every trace of barium chloride and ammonium chloride has been removed, a small quantity of the washings from the filter should be placed in a test-tube, and a drop of a solution of silver nitrate added. Should the liquid, instead of remaining perfectly clear, become cloudy, the washing must be continued until, on repeating the test, no cloudiness is produced.) Dry the filter with its contents, and transfer it into a weighed platinum crucible. Heat the crucible over a lamp, increasing the temperature gradually, from the point at which the paper begins to char, up to bright redness.* When no black particles remain, allow the crucible to cool; place it when nearly cold in a dessicator over strong sulphuric acid, and again weigh it. The difference between the first and second weighings of the crucible will give the number of grains of barium sulphate. Multiply this number by 11, and divide by 4; the result is the number of grains of sulphur in 100 cubic feet of the gas.

This number is to be corrected for the variations of temperature and atmospheric pressure in the manner indicated under the head of Illuminating Power, with this difference—that the readings of the barometer and thermometer are to be taken for the day on which the testing commenced, and also the day on which it closed; and the mean of the two is to be used.

---

* An equally good and more expeditious method is to drop the filter with its contents, drained but not dried, into the red-hot crucible.

This correction may be made most simply and with sufficient accuracy in the following manner :—

When the tabular number is between 955–965, 966–975, 976–985, 986-995 ; increase the number of grains of sulphur by $\frac{4}{100}$ths $\frac{3}{100}$ths $\frac{2}{100}$ths, $\frac{1}{100}$th.

When the tabular number is between 996–1005, no correction need be made.

When the tabular number is between 1006–1015, 1016–1025, 1026–1035, diminish the number of grains of sulphur by $\frac{1}{100}$th, $\frac{2}{100}$ths, $\frac{3}{100}$ths.

EXAMPLE :

| | |
|---|---|
| Barometer (mean) . | 29 4 |
| Thermometer (mean) | 58 |
| Tabular number . . | 985 |

Grains of barium sulphate from 5 cub. ft. of gas 4·3
Multiply by 11, and divide by 4.

4)47·3

Grains of sulphur in 100 cub. ft. of gas (uncorrected). . . . . . . . . . . . . 11·82
Add $11{\cdot}8 \times \frac{2}{100} =$ . . . . . . . . . . . . ·24

Grains of sulphur in 100 cub. ft. of gas (corrected) . . . . . . . . . . . . 12·06

Result :
12·1 grains.

As to the

MODE OF TESTING THE PRESSURE AT WHICH GAS IS SUPPLIED.

Testings of pressure shall be made by unscrewing the governor and burner of one of the ordinary public lamps, in such street or part of a street as the controlling authority may from time to time appoint, and attaching in their stead a portable pressure-gauge.

Each testing-place is provided with a gauge prescribed for this purpose by the Referees, consisting of an ordinary pressure-gauge enclosed in a lantern, which also holds a candle for throwing light upon the tubes and scale. The difference of level of the water in the two limbs of the gauge is read by means of a sliding scale, the zero of which is made to coincide with the top of the lower column of liquid.

The Gas Examiner having fixed the gauge gas-tight, and as nearly as possible vertical on the pipe of the lamp, and having opened the cocks of the lamp and gauge, shall read and at once record the pressure shown. From the observed pressure one-tenth of an inch is to be deducted to correct for the difference between the pressure of gas at the top

of the lamp-column and that at which it is supplied to the basement of neighbouring houses.

A drawing and description of the street lamp pressure-gauge are given in Appendix D.

METERS.

The meters used for measuring the gas consumed in making the various testings, having been certified by the Referees, shall, at periods of not less than seven days, be proved by the Gas Examiners by means of the Referees' Cubic-Foot Measure—a description of which apparatus, with directions how to use it, is given in Appendix F. Should a meter show any variation, water must be added or withdrawn until the meter is correct. Every testing-place shall have the above-mentioned apparatus, so that the Gas Examiner may employ it whenever he thinks necessary.

No meter other than a wet one shall be used in testing the gas under these instructions.

---

The results of the daily testings for illuminating power and purity shall be recorded in the form given in Appendix E, and delivered as provided in the Acts of Parliament.

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As to the

MAXIMUM AMOUNTS OF IMPURITY

in each form with which the gas shall be allowed to be charged.

*Sulphuretted Hydrogen.*

By the Acts of Parliament all gas supplied must be wholly free from this impurity.

*Ammonia.*

The maximum amount of this impurity shall be 4 grains per 100 cubic feet.

*Sulphur Compounds other than Sulphuretted Hydrogen.*

The maximum amount of sulphur with which gas shall be allowed to be charged shall be 17 grains of sulphur in every 100 cubic feet of gas.

These regulations shall be in force from the 31st of March, 1889, until superseded by a future Notification.

A. VERNON HARCOURT.
WILLIAM POLE.
JOHN TYNDALL.
Gas Referees.

## APPENDIX A.

The burner which has been adopted as the standard burner for testing common gas was designed by Mr. Sugg, and was called by him "Sugg's London Argand, No. 1."

An illustration, showing a section is appended, in which A represents a supply-pipe B, the gallery ; C, the cone ; D. the steatite chamber ; E, the chimney.

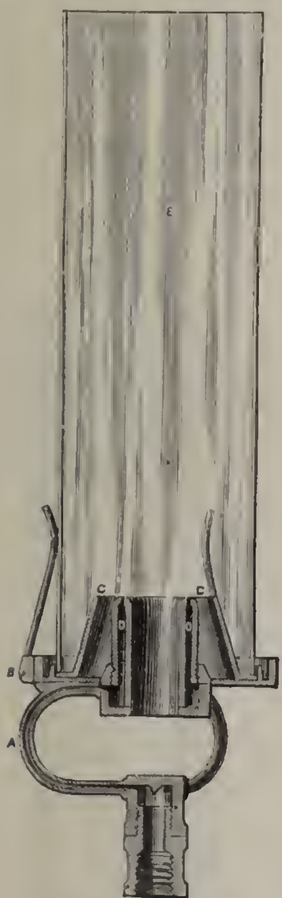


FIG. 26.—SUGG'S LONDON ARGAND.

The following are the dimensions of those parts of the burner upon which its action depends:—

| | Inch. |
|---|---|
| Diameter of supply-pipes . . . . . . . | 0·08 |
| External diameter of annular steatite chamber . . . . . . . . . . . . . | 0·84 |
| Internal diameter of do. . . . . . . . | 0·48 |
| Number of holes . . . . . . . . . . | 24 |
| Diameter of each hole . . . . . . . | 0·045 |
| Internal diameter of cone— | |
| At the bottom . . . . . . . . . . | 1·5 |
| At the top . . . . . . . . . . . | 1·08 |
| Height of upper surface of cone and of steatite chamber above floor of gallery | 0·75 |
| Height of glass chimney . . . . . . . | 6 |
| Internal diameter of chimney . . . . . | $1\frac{7}{8}$ |

The standard burner for testing cannel gas is a steatite batswing burner, consisting of a cylindrical stem, the top of which is divided by a slit of uniform width.

| | Inch. |
|---|---|
| External diameter of top of stem . . . . . . | 0·31 |
| Internal diameter of stem . . . . . . . . . | 0·17 |
| Width of slit . . . . . . . . . . . . . . | 0·02 |
| Depth of slit . . . . . . . . . . . . . . | 0·15 |

## APPENDIX B.

*The Gas Referees' Street-Lamp Pressure-Gauge.*

This instrument has been designed by us, in compliance with Section 6 of The Gaslight and Coke and other Gas Companies Acts Amendment Act, 1880, for the purpose of testing in any street at any hour the pressure at which gas is supplied. Its construction and mode of use are as follows:—

Within a lantern, provided with a handle for carrying and feet for resting on the ground, is placed a candle-lamp, to give light for reading the gauge. In front of the candle-lamp is a sheet of opal glass, and in front of this a glass U-tube, partly filled with coloured water, and communicating at one end with the air, at the other with a metal pipe, which passes through the bottom of the lantern. In order to read easily and accurately the difference of level of the liquid in the two limbs, a scale divided into tenths of an inch is made to slide between them with sufficient friction to retain it in any position. The zero of the scale having been brought level with the surface of the liquid which is pressed upon by the gas, the height above this of the surface which is pressed upon by the air can be read directly. The lantern is closed in front by a glass door, at each side of which is a reflector for throwing light upon the scale of the gauge. Above each limb of the U-tube is a tap which can be closed when the instrument is not in use, to prevent the liquid being accidentally spilt.

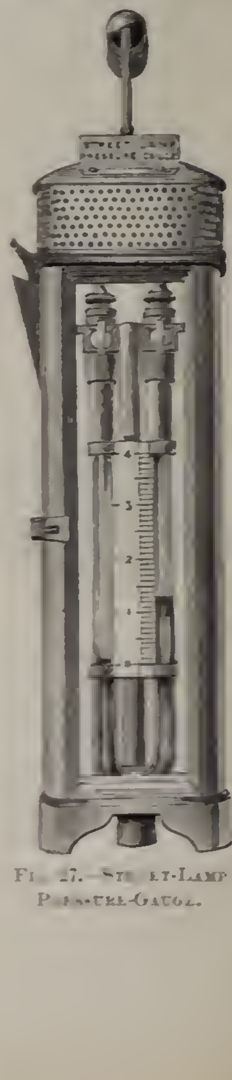


Fig. 27.—Street-Lamp Pressure-Gauge.

To make a testing of pressure, the governor and burner of a street lamp are to be removed, and the pressure-gauge is to be screwed on to the gas-pipe, by which it is supported. The cock is then turned on, and a reading made. If, on turning off the cock, the level of the liquid is unchanged, or changes slowly, the reading is correct; but if the level changes quickly, the junction between the lamp and the gauge must be made more perfect, and the testing repeated. A small leakage is immaterial, provided the cock is turned fully on.

The pressure at the top of a lamp column is greater by about 0·1 inch than that at the main, which is the pressure required. Accordingly, a deduction of 0·1 inch from the observed pressure is to be made.

## APPENDIX C.

*Table to facilitate the Correction of the Volume of Gas at*

| Bar. | Ther. 40° | 42° | 44° | 46° | 48° | 50° | 52° | 54° | 56° | 58° | 60° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 28·0 | ·979 | ·974 | ·970 | ·965 | ·960 | ·956 | ·951 | ·946 | ·942 | ·937 | ·932 |
| 28·1 | ·983 | ·978 | ·973 | ·969 | ·964 | ·959 | ·955 | ·951 | ·945 | ·941 | ·936 |
| 28·2 | ·986 | ·981 | ·977 | ·972 | ·967 | ·963 | ·958 | ·953 | ·949 | ·944 | ·939 |
| 28·3 | ·990 | ·985 | ·980 | ·976 | ·971 | ·966 | ·961 | ·957 | ·952 | ·947 | ·942 |
| 28·4 | ·993 | ·988 | ·984 | ·979 | ·974 | ·970 | ·965 | ·960 | ·955 | ·951 | ·946 |
| 28·5 | ·997 | ·992 | ·987 | ·983 | ·978 | ·973 | ·968 | ·964 | ·959 | ·954 | ·949 |
| 28·6 | 1·001 | ·995 | ·991 | ·986 | ·981 | ·977 | ·972 | ·967 | ·962 | ·958 | ·953 |
| 28·7 | 1·004 | ·999 | ·994 | ·990 | ·985 | ·980 | ·975 | ·970 | ·966 | ·961 | ·956 |
| 28·8 | 1·007 | 1·003 | ·998 | ·993 | ·988 | ·984 | ·979 | ·974 | ·969 | ·964 | ·959 |
| 28·9 | 1·011 | 1·006 | 1·001 | ·997 | ·992 | ·987 | ·982 | ·977 | ·973 | ·968 | ·963 |
| 29·0 | 1·014 | 1·010 | 1·005 | 1·000 | ·995 | ·990 | ·986 | ·981 | ·976 | ·971 | ·966 |
| 29·1 | 1·018 | 1·013 | 1·008 | 1·004 | ·999 | ·994 | ·989 | ·984 | ·979 | ·975 | ·969 |
| 29·2 | 1·021 | 1·017 | 1·012 | 1·007 | 1·002 | ·997 | ·992 | ·988 | ·982 | ·978 | ·973 |
| 29·3 | 1·025 | 1·020 | 1·015 | 1·011 | 1·006 | 1·001 | ·996 | ·991 | ·986 | ·981 | ·976 |
| 29·4 | 1·028 | 1·024 | 1·019 | 1·014 | 1·009 | 1·004 | ·999 | ·995 | ·990 | ·985 | ·980 |
| 29·5 | 1·032 | 1·027 | 1·022 | 1·018 | 1·013 | 1·008 | 1·003 | ·998 | ·993 | ·988 | ·983 |
| 29·6 | 1·036 | 1·031 | 1·026 | 1·021 | 1·016 | 1·011 | 1·006 | 1·001 | ·996 | ·992 | ·986 |
| 29·7 | 1·039 | 1·034 | 1·029 | 1·025 | 1·019 | 1·015 | 1·010 | 1·005 | 1·000 | ·995 | ·990 |
| 29·8 | 1·043 | 1·038 | 1·033 | 1·028 | 1·023 | 1·018 | 1·013 | 1·008 | 1·003 | ·998 | ·993 |
| 29·9 | 1·046 | 1·041 | 1·036 | 1·031 | 1·026 | 1·022 | 1·017 | 1·012 | 1·007 | 1·002 | ·997 |
| 30·0 | 1·050 | 1·045 | 1·040 | 1·035 | 1·030 | 1·025 | 1·020 | 1·015 | 1·010 | 1·005 | 1·000 |
| 30·1 | 1·053 | 1·048 | 1·043 | 1·038 | 1·033 | 1·029 | 1·024 | 1·019 | 1·014 | 1·009 | 1·003 |
| 30·2 | 1·057 | 1·052 | 1·047 | 1·042 | 1·037 | 1·032 | 1·027 | 1·022 | 1·017 | 1·012 | 1·007 |
| 30·3 | 1·060 | 1·055 | 1·050 | 1·045 | 1·040 | 1·036 | 1·030 | 1·025 | 1·020 | 1·015 | 1·010 |
| 30·4 | 1·064 | 1·059 | 1·054 | 1·049 | 1·044 | 1·039 | 1·034 | 1·029 | 1·024 | 1·019 | 1·014 |
| 30·5 | 1·067 | 1·062 | 1·057 | 1·052 | 1·047 | 1·042 | 1·037 | 1·032 | 1·027 | 1·022 | 1·017 |
| 30·6 | 1·071 | 1·066 | 1·061 | 1·056 | 1·051 | 1·046 | 1·041 | 1·036 | 1·031 | 1·026 | 1·020 |
| 30·7 | 1·074 | 1·069 | 1·064 | 1·059 | 1·054 | 1·049 | 1·044 | 1·039 | 1·034 | 1·029 | 1·024 |
| 30·8 | 1·078 | 1·073 | 1·068 | 1·063 | 1·058 | 1·053 | 1·048 | 1·043 | 1·037 | 1·032 | 1·027 |
| 30·9 | 1·081 | 1·076 | 1·071 | 1·066 | 1·061 | 1·056 | 1·051 | 1·046 | 1·041 | 1·036 | 1·031 |
| 31·0 | 1·085 | 1·080 | 1·075 | 1·070 | 1·065 | 1·060 | 1·055 | 1·049 | 1·044 | 1·039 | 1·034 |

*_* The numbers in the above table have been calculated from the formula $n = \frac{17·64\,(h-a)}{460\,+\,t}$

tension of aqueous vapour at $t°$. If $v$ is any volume at $t°$ and $h$ inches pressure,

*different Temperatures and under different Atmospheric Pressures.*

| Bar. | Ther. 62° | 64° | 66° | 68° | 70° | 72° | 74° | 76° | 78° | 80° | 82° | 84° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28·0 | ·927 | ·922 | ·917 | ·912 | ·907 | ·902 | ·897 | ·892 | ·887 | ·881 | ·875 | ·870 |
| 28·1 | ·930 | ·926 | ·921 | ·916 | ·911 | ·905 | ·900 | ·895 | ·890 | ·884 | ·879 | ·873 |
| 28·2 | ·934 | ·929 | ·924 | ·919 | ·914 | ·909 | ·904 | ·898 | ·893 | ·887 | ·882 | ·876 |
| 28·3 | ·937 | ·932 | ·928 | ·922 | ·917 | ·912 | ·907 | ·902 | ·896 | ·891 | ·885 | ·880 |
| 28·4 | ·941 | ·936 | ·931 | ·926 | ·921 | ·915 | ·910 | ·905 | ·900 | ·894 | ·888 | ·883 |
| 28·5 | ·944 | ·939 | ·934 | ·929 | ·924 | ·919 | ·914 | ·908 | ·903 | ·897 | ·892 | ·886 |
| 28·6 | ·947 | ·943 | ·938 | ·932 | ·927 | ·922 | ·917 | ·912 | ·906 | ·901 | ·895 | ·889 |
| 28·7 | ·951 | ·946 | ·941 | ·936 | ·931 | ·925 | ·920 | ·915 | ·909 | ·904 | ·898 | ·893 |
| 28·8 | ·954 | ·949 | ·944 | ·939 | ·934 | ·929 | ·924 | ·918 | ·913 | ·907 | ·901 | ·896 |
| 28·9 | ·958 | ·953 | ·948 | ·942 | ·937 | ·932 | ·927 | ·921 | ·916 | ·910 | ·905 | ·899 |
| 29·0 | ·961 | ·956 | ·951 | ·946 | ·941 | ·935 | ·930 | ·925 | ·919 | ·914 | ·908 | ·903 |
| 29·1 | ·964 | ·959 | ·954 | ·949 | ·944 | ·939 | ·933 | ·928 | ·923 | ·917 | ·911 | ·906 |
| 29·2 | ·968 | ·963 | ·958 | ·952 | ·947 | ·942 | ·937 | ·931 | ·926 | ·920 | ·914 | ·909 |
| 29·3 | ·971 | ·966 | ·961 | ·956 | ·950 | ·945 | ·940 | ·935 | ·929 | ·923 | ·918 | ·912 |
| 29·4 | ·975 | ·969 | ·964 | ·959 | ·954 | ·949 | ·943 | ·938 | ·932 | ·927 | ·921 | ·915 |
| 29·5 | ·978 | ·973 | ·968 | ·962 | ·957 | ·952 | ·947 | ·941 | ·936 | ·930 | ·924 | ·919 |
| 29·6 | ·981 | ·976 | ·971 | ·966 | ·960 | ·955 | ·950 | ·944 | ·939 | ·933 | ·927 | ·922 |
| 29·7 | ·985 | ·980 | ·974 | ·969 | ·964 | ·959 | ·953 | ·948 | ·942 | ·937 | ·931 | ·925 |
| 29·8 | ·988 | ·983 | ·978 | ·972 | ·967 | ·962 | ·957 | ·951 | ·946 | ·940 | ·934 | ·928 |
| 29·9 | ·991 | ·986 | ·981 | ·976 | ·970 | ·965 | ·960 | ·954 | ·949 | ·943 | ·937 | ·932 |
| 30·0 | ·995 | ·990 | ·985 | ·979 | ·974 | ·968 | ·963 | ·958 | ·952 | ·946 | ·941 | ·935 |
| 30·1 | ·998 | ·993 | ·988 | ·983 | ·977 | ·972 | ·966 | ·961 | ·955 | ·950 | ·944 | ·938 |
| 30·2 | 1·002 | ·996 | ·991 | ·986 | ·980 | ·975 | ·970 | ·964 | ·959 | ·953 | ·947 | ·941 |
| 30·3 | 1·005 | 1·000 | ·995 | ·989 | ·984 | ·978 | ·973 | ·968 | ·962 | ·956 | ·950 | ·945 |
| 30·4 | 1·008 | 1·003 | ·998 | ·993 | ·987 | ·982 | ·976 | ·971 | ·965 | ·959 | ·954 | ·948 |
| 30·5 | 1·012 | 1·006 | 1·001 | ·996 | ·990 | ·985 | ·980 | ·974 | ·969 | ·963 | ·957 | ·951 |
| 30·6 | 1·015 | 1·010 | 1·005 | ·999 | ·994 | ·988 | ·983 | ·977 | ·972 | ·966 | ·960 | ·954 |
| 30·7 | 1·018 | 1·013 | 1·008 | 1·003 | ·997 | ·992 | ·986 | ·981 | ·975 | ·969 | ·963 | ·957 |
| 30·8 | 1·022 | 1·017 | 1·011 | 1·006 | 1·000 | ·995 | ·990 | ·984 | ·978 | ·972 | ·967 | ·961 |
| 30·9 | 1·025 | 1·020 | 1·015 | 1·009 | 1·004 | ·998 | ·993 | ·987 | ·982 | ·976 | ·970 | ·964 |
| 31·0 | 1·029 | 1·023 | 1·018 | 1·013 | 1·007 | 1·002 | ·996 | ·991 | ·985 | ·979 | ·973 | ·967 |

where $h$ is the height of the barometer in inches, $t$ the temperature on the Fahrenheit scale, and $a$ the and V the corre ponding volume at 60° and 30 inches pressure, V = $v$ $n$.

## APPENDIX D.

*Testings for Illuminating Power.*

*Date* 188

Barometer ............ Thermometer ............ Tabular number

| Hour. | ...... | ...... | ...... |
|---|---|---|---|
| | Consumption of sperm by two candles in ten minutes .. } ...... | Consumption of sperm by two candles in ten minutes .. } ...... | Consumption of sperm by two candles in ten minutes .. } ...... |
| | *Observations.* | *Observations.* | *Observations.* |
| Observations taken at intervals of one minute. | 1st min. ........ | 1st min. ........ | 1st min. ........ |
| | 2nd ,, ........ | 2nd ,, ........ | 2nd ,, ........ |
| | 3rd ,, ........ | 3rd ,, ........ | 3rd ,, ........ |
| | 4th ,, ........ | 4th ,, ........ | 4th ,, ........ |
| | 5th ,, ........ | 5th ,, ........ | 5th ,, ........ |
| | 6th ,, ........ | 6th ,, ........ | 6th ,, ........ |
| | 7th ,, ........ | 7th ,, ........ | 7th ,, ........ |
| | 8th ,, ........ | 8th ,, ........ | 8th ,, ........ |
| | 9th ,, ........ | 9th ,, ........ | 9th ,, ........ |
| | 10th ,, ........ | 10th ,, ........ | 10th ,, ........ |
| Re-multiply the number obtained by the number of grains consumed by the two candles in ten minutes, and divide by 2. Or divide by the number of minutes in which 40 grains were consumed. | ........ | ........ | ........ |
| | 2) | 2) | 2) |

| | | |
|---|---|---|
| Illuminating Power at . . | .... | ........ |
| ,, ,, . . | .... | ........ |
| ,, ,, . . | .... | ........ |

Tabular number.... ) ...... ( ....=*Corrected* Average Illuminating Power for the day.

Divide the average Illuminating Power by the tabular number corresponding to mean Temperature and Pressure; the quotient will be the corrected Illuminating Power for the day.

Average Illuminating Power, uncorrected } = ............ Candles.

............

*Gas Examiner.*

## APPENDIX E.

METROPOLITAN GAS-TESTING STATION,
1, CARLYLE SQUARE, CHELSEA, S.W.

REPORT ON GAS SUPPLIED BY THE GASLIGHT AND COKE COMPANY.

COMMON GAS.

| Date. | Mean Lighting Power, in Candles, corrected. | Sulphur in 100 cubic feet of Gas, in Grains. | Sulphuretted Hydrogen. | Ammonia in 100 cubic feet of Gas, in Grains. | Testing of Pressure. |
|---|---|---|---|---|---|
| | | | | | *Time—* |
| | | | | | *Pressure—* |
| | | | | | *Street—* |

........

*Gas Examiner.*

## APPENDIX F.

### THE GAS REFEREES' CUBIC-FOOT MEASURE.

*Description of the Cubic-Foot Measure; the method of fixing it; and directions for verifying the accuracy of the meters connected with the Photometer, and with the sulphur and ammonia tests.*

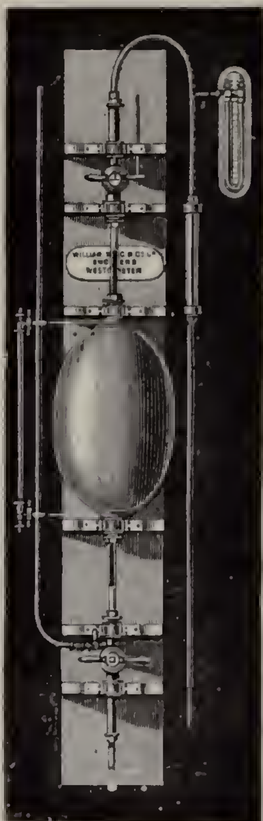


Fig. 28.—Cubic-Foot Measure, with Water-Level Indicator.

This instrument is a vessel in form like an elongated egg, made of hardened tin about one-quarter of an inch thick, fitted at each end with a narrow glass tube; the joints being made sound with india-rubber packing The instrument stands in a vertical position firmly fixed to a strong plank.

At the top of the instrument is a three-way cock, marked on the head of the key with a T, each arm of which shows the direction of a way through the plug and in the side of this cock there is a small hole or vent, which serves to admit the air when the measure is to be emptied of water. When the T is in its ordinary position, communication is closed between the measure and the tube leading from it to the meters, but is open to the external air. With the ⊣ in this position (*i.e.*, with the stem pointing to the *opposite* side of the cock to that in which the vent is drilled), the measure is open to the meters and shut to the air. This air-vent is now connected to the gas supply.

At the bottom of the instrument there are two cocks —the small one, when opened admits water into the measure; the large one, when opened, allows the water to be run off. The former of these cocks is provided with a lever-key, in order to regulate with greater nicety the entrance of the water into the measure.

The cock at the top of the measure is continued by a tin pipe in the form of an arch (bending down to meet the pipe leading to the meters); and at the further end of the arch there is a piece of glass tube, in which a thermometer is hung to show the temperature of the air passing from the measure into the meter.

Affixed round each of the glass tubes fitted to the upper and lower part of the measure, there is a narrow strip of paper, which indicates the exact measure of one cubic foot, as tested by the Exchequer standard cubic-foot bottle; the upper edge of both strips of paper being the true water-line of the measure.

The instrument should be in communication with a tank of water in the same room.

To verify the meters employed in ascertaining the consumption of gas in the Photometers, or those employed in the sulphur and ammonia tests, the mode of procedure is as follows :—

Starting with the bottle full of water, turn the three-way cock at the top of the instrument so as to place the measure in communication with the gas-supply from the main, and open the large cock at the bottom of the apparatus. When the bottle is filled with gas, close the large cock and open the small lever-cock, and allow sufficient water to flow in to fill the lower glass tube up to the water-line. Then turn the upper three-way cock so as to close the inlet for gas, while opening the way to the meters.

Next turn the cock of the meter which is to be tested so as to cut off the ordinary gas supply, and to place the meter in communication with the cubic-foot measure, taking care that all the other meters are closed to the cubic-foot measure. See that the tap is open which allows gas to pass from the meter through the governor to the burner. Note the exact position of the index hands—*i.e.*, both the long hand and the 1-foot hand if it be a Photometer meter, or simply the hand on the upper dial if it be a sulphur meter.

Then proceed gently to open the small lever-cock, and allow the water to flow into the measure, just fast enough to raise the pressure in the syphon pressure-gauge fixed alongside, and in communication with the measure, from half an inch to three-quarters. This precaution is necessary to prevent the water being blown out of the meter by excessive pressure.

A meter attached to the Photometer should make twelve revolutions of the long hand, and consequently one of the cubic-foot hand, by the time the measure is full up to the strip of paper on the upper glass tube. A meter connected with the sulphur test should, in the same time, make one revolution of the long hand.

Should the meter complete the prescribed number of revolutions before the measure is full, then some water must be removed from the meter ; if the contrary is the case, then water must be added to the meter. The testing is then to be repeated until the meter is found to register correctly.

The dial of the Photometer meter is divided into 50 divisions ; and as each revolution indicates one-twelfth of a foot, each division consequently represents the $\frac{1}{600}$ part of a cubic foot ; and therefore six of those divisions represent 1 per cent.

The dial of the sulphur meters is divided into 100 parts ; and as each complete revolution indicates one foot, each division consequently represents 1 per cent.

When the temperature of the cubic-foot measure is higher than the temperature at the outlet of the meter, the meter (if correct) will register a smaller quantity than has actually passed to it from the measure ; when the temperature of the measure is lower than that of the meter, the quantity registered ought to be greater.

To find the volume which the meter ought to register, when such a difference of temperature exists, divide the tabular number corresponding to the barometric pressure and the temperature of the cubic-foot measure by the tabular number corresponding to the barometric pressure and the temperature of meter.

## REVISED REGULATIONS AS TO GAS-MEASURING STANDARDS.

### I.—General Regulations.

The name of the local authority or company for whom a standard is required should be engraved on a brass plate, which is to be fixed on the front of the standard.

Standards for the use of local authorities and gas companies may be sent to the Standards Office for verification and stamping on any day, not being a public holiday, between the hours of 11 a.m. and 3 p.m.

Before standards are sent for verification, a requisition should be sent to the Department, describing the standard, and stating for whose use it is required. Copies of a requisition (Form A 2) may be had on application.

So soon as the standard is verified, the local authority or gas company named in the requisition will be duly notified.

The screw-threads of all pipes, connections, or caps and linings on gas-measuring standards, are to agree in diameter and in the number of threads per inch with the standard sizes approved by the Department.

No repair or re-adjustment of a standard can be made at this Office, although the officers here will render every assistance in their power to facilitate the verification of standards.

No fees are payable on the verification or stamping of gas standards.

### II.—Stamping of Standards.

*Local Standards.*—Only standard gasholders, gas-meters, or photometers for local authorities are stamped with the *official* stamp of the Department, as follows:—

*Standards for Gas Companies.*—Test gasholders, meters, and photometers, for the use of gas companies and others (not being standards for the use of any local authority) bear the following stamp:—


This last stamp gives no legal authority whatever to the gasholder or meter or photometer, but is only a guarantee of its accuracy. Instruments so stamped cannot, of course, be used either in place of, or in addition to, or in substitution for any standard issued to a local authority.

Secondary standards, not being standards for the use of Inspectors, may be verified at Edinburgh for use in Scotland, under the directions of the Standards Department. Such secondary standards then bear the following stamp:—


### III.—Gas-Meters.

The standard gas-meter to be used in testing ordinary meters (in place of a gasholder) should be a wet meter; and it may be of any capacity up to 100 lights. Although it is desirable that in form and general arrangement it should be a copy of the Board of Trade model, yet no meter will be refused for verification which may differ from the model either in form or external dimensions, in fittings, or in the graduation of the dial.

The meter should, however, always be fitted with—

1. An adjustable "overflow" both in the back and front of the meter. The position of these "overflows" will be adjusted and sealed at this office.

2. A glass gauge or window, on which the true water-line will be marked at this office.
3. A cross spirit-level on the top of the meter, by which the level of the meter may be always ascertained.
4. A dial to show at least one-hundredth of a cubic foot.
5. The meter should have an outlet tap or valve.

The true water-line will be marked at this Office on the meter when it is passing its normal capacity per hour under a pressure on its inlet of 5-10ths of an inch; and the meter will be tested according to the following rules:—

*Rules for Testing Standard Meters.*

1. For soundness, under 3 inches pressure.
2. For steadiness of light, when burning gas at the rate per hour marked on the meter.
3. For accuracy of measurement—
   *a.* When passing 6 feet, or one light per hour, at a pressure of 1 inch.
   *b.* When passing the whole quantity per hour marked on the meter, under a pressure of 5-10ths.
   *c.* When passing the whole quantity per hour marked on the meter, under a pressure of 2 inches.
   *d.* When passing double the quantity per hour marked on the meter, under a pressure of 2 inches.
4. Examination of index and registering apparatus.

If the meter is found to pass the above tests, it will be stamped as correct.

IV.—Gasholders.

1. *Form.*—From and after the date of these regulations, every gasholder should be similar in general form to the models deposited at this office, and should be made of suitable metal.

2. *Scales.*—The bell may have either two vertical scales, or one vertical scale only. If one vertical scale only is provided, a cross spirit-level is to be fixed on the top of the bell, so that the bell may always be used in the same vertical position.

The scales should be graduated throughout into cubic feet, and decimal sub-divisions of a cubic foot, in the same way as the models.

For the accurate reading of each scale there must be firmly attached to the gasholder tank a pointer or a telescope.

3. *Error.*—No variation from true standard of more than one-quarter per centum either in excess or in deficiency will be allowed on any standard gasholder.

4. *Pressure-Gauge.*—A pressure-gauge is to be fixed either on the top of the bell, or on the outlet-pipe of the gasholder.

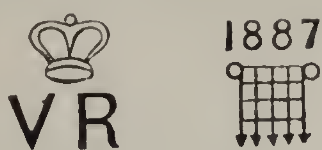
5. *Thermometer.*—An accurate Fahrenheit thermometer is to be also fixed either on the top of the bell, or on the outlet-pipe of the gasholder.

6. *Balance.*—The bell must be exactly balanced either by a cycloidal counterpoise, or by other approved means, at all depths of immersion in the water of the tank.

### V.—Standard Burners and Photometers.

Any standard burner or photometer, either for the use of a local authority, or for a gas company, will be received for examination if it is of a form prescribed in an Act, or of a form approved by the Metropolis Gas Referees. A descriptive certificate is issued with a verified photometer, but not with a standard burner.

Where in any Act of Parliament the President of the Board of Trade or the Board of Trade are required to certify a model or standard burner, the only mode in which such certificate is given is by means of the following stamp :—




The denomination only of the burner should be engraved on it, and also on its chimney, as "16 candles," "18 candles."

*Board of Trade,*

*Standards Office,*

7, *Old Palace Yard, Westminster, S.W.,*

*March* 1, 1887.

## SALE OF GAS ACT.

### GAS-METER TESTING.

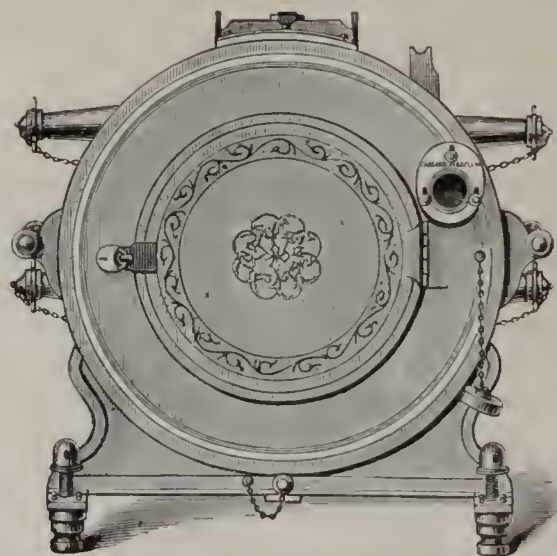


Fig. 29.

Experience has shown that the standard "gasholder," which is used by the inspector of gas-meters in testing ordinary meters brought to his office, cannot be accurately and conveniently used in testing *in situ* those large meters which may not be removed from the places where they are used. In 1871 the Standards Department, at the recommendation of the Standards Commission, caused to be made and legalized certain standard test-meters which have since served as models under the Act. It has been represented, however, by some of the principal inspectors that these models are not sufficiently portable, and other models of a better form have, therefore, now been made and duly verified.

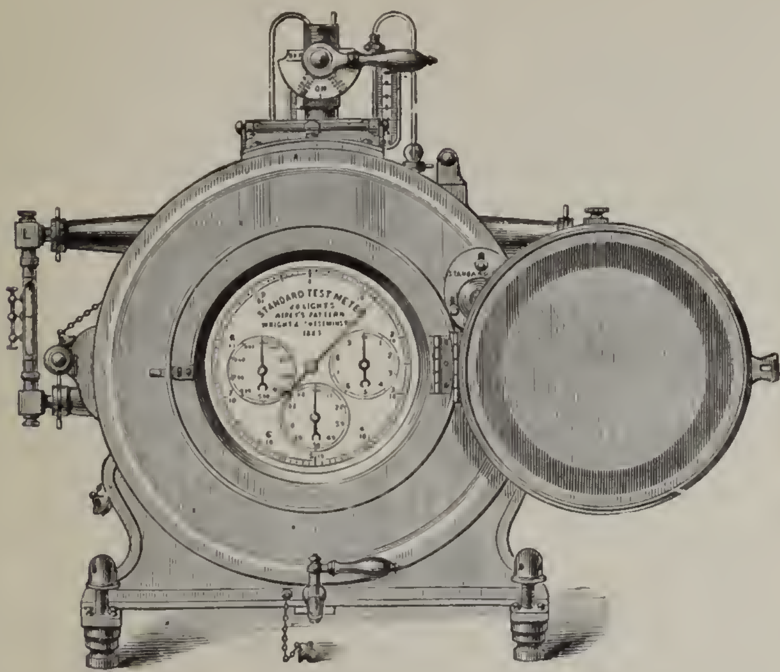



Fig. 30.

The form of the new 20-light model test-meter is shown as above. Fig. 29 shows the meter dismounted ready for travelling, the outlet-pipe and all projecting parts liable to injury in transit having been removed and placed in a small tin case which accompanies the meter. Fig. 30 shows the meter mounted ready for use, with the water-gauges, levels, and outlet-pipe attached. The weight of this meter dismounted is 70 lbs. It will, of course, pass through any ordinary doorway; and its cost with fittings complete should not exceed £35. It is adapted for testing any meter from 20 lights to 100 lights; a large standard of nominally 100 lights being necessary for testing larger meters.

The standard meter has levelling screws, and is provided with the following external fittings:—Two water-level gauges, one on each side; two spirit-levels resting in cradles on the top of the meter; two pressure-gauges, one in communication with inlet and the other with outlet; two thermometers, one on the meter to indicate temperature at outlet, the other on the top of the inlet connection; a regulating-cock

with lever placed centrally on the top; a draw-off water cock at the base in front. All these external fittings can be easily detached from the meter when it is being carried, and fitted in the small tin case above referred to. The points to which the gauges, &c., are attached are furnished with screwed caps, secured against loss by short suspension chains, and, on the removal of the fittings, these caps may be quickly screwed over the points.

In addition to the water-line gauges, the meter is provided at opposite sides, back and front, with adjusting overflow sockets, so shaped as to prevent any "piling" of the water above the "weir" over which water is to flow. These sockets are carried on plates slotted vertically; each plate being secured by three screws to the back and front of the meter. With the meter truly level and charged with water, the positions of the overflow sockets are determined when the meter is first verified, and then the screws are tightened; the correct positions being such that water shall cease to flow or drip out when the above level agrees with that indicated by the water-line gauges. Thereafter, when the meter is to be used, it will only be necessary, in order to ensure the correct water-line, to set the meter truly level, by the aid of its feet-screws and spirit-levels. In the event of the glass gauges being broken in transit, the meter can also then always be filled to its true water-line.

The pointer of each index on the dial is fixed by a screw, by loosening which the pointer can be shifted and the index promptly set to zero.

The gauges, &c., are all marked R, or L, (right, or left), so that no delay in fixing may arise.

If the test-meter is worked much above its normal speed of 120 revolutions per hour, a small error in registration will ensue, for which the inspector can allow.

The method of using a test-meter is so well known to inspectors that it is not deemed necessary to give details, more especially as published information exists; but it may be pointed out that it is desirable that the gas should first pass through the meter to be tested and then through the standard, and that the standard should be placed as near to the meter as possible, so as to assure uniformity of temperature The primary conditions for use being also—(*a*) that the meter shall be adjusted to its standard level; (*b*) that it shall be charged to the exact water-line with water; (*c*) that it shall as far as prac icable be

worked at its normal speed—viz., 120 revolutions per hour, corresponding for—

| | | Per Hour. | Per Minute. |
|---|---|---|---|
| A 20-light test-meter | to | 120 cub. ft. or | 2 cub. ft. |
| A 100-light ,, | to | 600 ,, or | 10 ,, |

It is necessary that every local authority under this Act should provide their inspectors with duly verified copies of these models. No meters can be legally tested outside the inspectors' offices, or fees received for such testings, unless the testings have been made with standards verified by this Department.

*Board of Trade,*
*Standards Department,*
*August*, 1884.

## STANDARD GAUGES FOR THE CONNECTING-PIPES AND FITTINGS USED WITH GAS-METERS.

In consequence of some representations made to the Standards Department by engineers and manufacturers as to a want of uniformity in the sizes and screw-threads of the connecting-pipes and fittings (caps and linings, unions, &c.) used with gas-meters, it has been deemed desirable to obtain information as to the actual sizes of the pipes and screw-threads now in use by the principal gas companies and meter manufacturers. It would appear from the results of the inquiries, that the sizes of the connections or unions adopted by different companies and manufacturers vary considerably; and that unnecessary expense and inconvenience are occasioned by the want of uniformity. It is evident that a common understanding in this matter of detail has not hitherto been arrived at, owing to conflicting trade interests.

If practical accuracy of fit and interchangeability of parts are to be attained, then engineers will adopt only approved standard sizes; and manufacturers will check their pipes and meter-connections, by the use in the workshop of standard gauges. Such standard gauges are not costly; and their accuracy can, of course, always be authoritatively tested.

Should those practically interested decide on the several sizes they might prefer to adopt, standards of such sizes may, if the Board of Trade so approve, be legalized by Order in Council; and it might then become illegal for any inspector of gas-meters to stamp a meter having unions or connections the sizes of which differed from those set out in such Order in Council.

The results of the above inquiries show that some of the principal gas companies, including The Gaslight and Coke Company of London, have adopted certain sizes approaching those stated in the attached list [see next page], and that it would be desirable to learn the opinion of engineers and manufacturers generally as to the expediency of adopting such sizes for official and trade purposes.

H. J. Chaney.

*Board of Trade, Standards Office, May*, 1887.

## STANDARD CONNECTING-PIPES AND FITTINGS.

*Proposed Board of Trade Standards for the Connecting-Pipes and Fittings used with Gas-Meters.*

| Size of Meter. | Size of Connecting-Pipe or Union of Gas-Meter. | | | | | | |
|---|---|---|---|---|---|---|---|
| | Boss. | | | Cap. | | | Lining. |
| | Mean Diameter of External Screw. | Number of Threads per Inch. | External Diameter Shank. | Mean Diameter of Internal Screw. | Number of Threads per Inch. | Height of Cap. | External Diameter. |
| Lights. | Inches. | | Inches. | Inches. | | Inches. | Inches. |
| 150 | 3·70 | 11 | 3·10 | 3·55 | 11 | 1·20 | 3·10 |
| 100 } 80 } | 3·10 | 11 | 2·40 | 3·00 | 11 | 1·00 | 2·40 |
| 60 | 2·45 | 11 | 2·10 | 2·35 | 11 | 0·80 | 2·10 |
| 50 | 2·25 | 11 | 1·85 | 2·15 | 11 | 0·70 | 1·85 |
| 30 | 2·05 | 11 | 1·60 | 2·00 | 11 | 0·70 | 1·60 |
| 20 | 1·85 | 11 | 1·40 | 1·80 | 11 | 0·60 | 1·40 |
| 10 | 1·45 | 11 | 1·10 | 1·40 | 11 | 0·60 | 1·10 |
| 5 | 1·15 | 12 | 0·85 | 1·10 | 12 | 0·50 | 0·85 |
| 3 } 2 } | 0·98 | 18 | 0·70 | 0·94 | 18 | 0·50 | 0·70 |
| 1 | 0·88 | 20 | 0·60 | 0·84 | 20 | 0·40 | 0·60 |
| 0 | 0·70 | 20 | 0·50 | 0·66 | 20 | 0·40 | 0·50 |

# CARCEL

*Giving the Weight of Oil burned per hour calculated*

| Time required to burn 10 Grms. of Oil. | Rate of Consumption per Hour. Grms. | Relation to the Carcel Lamp burning 42 Grms. of Oil per Hour. | Time required to burn 10 Grms. of Oil. | Rate of Consumption per Hour. Grms. | Relation to the Carcel Lamp burning 42 Grms. of Oil per Hour. | Time required to burn 10 Grms. of Oil. | Rate of Consumption per Hour. Grms. | Relation to the Carcel Lamp burning 42 Grms. of Oil per Hour. |
|---|---|---|---|---|---|---|---|---|
| Min. Sec. | | | Min. Sec. | | | Min. Sec. | | |
| 13 0 | 46·15 | 1·0989 | 13 30 | 44·46 | 1·0582 | 14 0 | 42·86 | 1·0204 |
| 13 1 | 46·09 | 1·0975 | 13 31 | 44·39 | 1·0569 | 14 1 | 42·81 | 1·0192 |
| 13 2 | 46·03 | 1·0961 | 13 32 | 44·33 | 1·0556 | 14 2 | 42·76 | 1·0180 |
| 13 3 | 45·98 | 1·0947 | 13 33 | 44·28 | 1.0543 | 14 3 | 42·70 | 1·0168 |
| 13 4 | 45·92 | 1·0933 | 13 34 | 44·23 | 1·0530 | 14 4 | 42·65 | 1·0156 |
| 13 5 | 45·86 | 1·0919 | 13 35 | 44·17 | 1·0517 | 14 5 | 42 60 | 1·0144 |
| 13 6 | 45·80 | 1·0905 | 13 36 | 44·12 | 1·0504 | 14 6 | 42·55 | 1·0132 |
| 13 7 | 45·74 | 1·0891 | 13 37 | 44·06 | 1·0491 | 14 7 | 42·50 | 1·0120 |
| 13 8 | 45·68 | 1·0877 | 13 38 | 44·01 | 1·0479 | 14 8 | 42·45 | 1·0108 |
| 13 9 | 45·62 | 1·0864 | 13 39 | 43·96 | 1·0466 | 14 9 | 42·40 | 1·0096 |
| 13 10 | 45·57 | 1·0850 | 13 40 | 43·90 | 1·0453 | 14 10 | 42·35 | 1·0084 |
| 13 11 | 45·51 | 1·0836 | 13 41 | 43·85 | 1·0440 | 14 11 | 42·30 | 1·0072 |
| 13 12 | 45·45 | 1·0823 | 13 42 | 43·80 | 1·0428 | 14 12 | 42·25 | 1·0060 |
| 13 13 | 45·40 | 1·0809 | 13 43 | 43·74 | 1·0415 | 14 13 | 42·20 | 1·0049 |
| 13 14 | 45·34 | 1·0795 | 13 44 | 43·69 | 1·0402 | 14 14 | 42·15 | 1·0037 |
| 13 15 | 45·28 | 1·0782 | 13 45 | 43·64 | 1·0390 | 14 15 | 42·10 | 1·0025 |
| 13 16 | 45·22 | 1·0768 | 13 46 | 43·58 | 1·0377 | 14 16 | 42·06 | 1·0013 |
| 13 17 | 45·16 | 1·0755 | 13 47 | 43·53 | 1·0364 | 14 17 | 42·01 | 1·0002 |
| 13 18 | 45·11 | 1·0741 | 13 48 | 43·48 | 1·0352 | 14 18 | 41·96 | 0·9990 |
| 13 19 | 45·06 | 1·0728 | 13 49 | 43·42 | 1·0339 | 14 19 | 41·91 | 0·9978 |
| 13 20 | 45·00 | 1·0714 | 13 50 | 43·37 | 1·0327 | 14 20 | 41·86 | 0·9967 |
| 13 21 | 44·94 | 1·0701 | 13 51 | 43·32 | 1·0315 | 14 21 | 41·81 | 0·9955 |
| 13 22 | 44·88 | 1·0687 | 13 52 | 43·27 | 1·0302 | 14 22 | 41·76 | 6·9944 |
| 13 23 | 44·83 | 1·0674 | 13 53 | 43·22 | 1·0290 | 14 23 | 41·71 | 0·9932 |
| 13 24 | 44·78 | 1·0661 | 13 54 | 43·16 | 1·0277 | 14 24 | 41·66 | 0·9921 |
| 13 25 | 44·72 | 1·0648 | 13 55 | 43·11 | 1·0265 | 14 25 | 41·61 | 0·9909 |
| 13 26 | 44 66 | 1·0635 | 13 56 | 43·06 | 1·0253 | 14 26 | 41·57 | 0·9898 |
| 13 27 | 44·61 | 1·0621 | 13 57 | 43·01 | 1·0241 | 14 27 | 41·52 | 0·9886 |
| 13 28 | 44·55 | 1·0608 | 13 58 | 42·96 | 1·0228 | 14 28 | 41·47 | 0·9875 |
| 13 29 | 44·50 | 1·0595 | 13 59 | 42·91 | 1·0216 | 14 29 | 41·42 | 0·9864 |

# LAMP.

*from the Time occupied in Burning Ten Grammes.*

| Time required to burn 10 Grms. of Oil. | Rate of Consumption per Hour. Grms. | Relation to the Carcel Lamp burning 42 Grms. of Oil per Hour. | Time required to burn 10 Grms. of Oil. | Rate of Consumption per Hour. Grms. | Relation to the Carcel Lamp burning 42 Grms. of Oil per Hour. | Time required to burn 10 Grms. of Oil. | Rate of Consumption per Hour. Grms. | Relation to the Carcel Lamp burning 42 Grms. of Oil per Hour. |
|---|---|---|---|---|---|---|---|---|
| Min. Sec. | | | Min. Sec. | | | Min. Sec. | | |
| 14 30 | 41·37 | 0·9852 | 15 0 | 40·00 | 0·9524 | 15 30 | 38·71 | 0·9217 |
| 14 31 | 41·33 | 0·9841 | 15 1 | 39·96 | 0·9513 | 15 31 | 38·67 | 0·9207 |
| 14 32 | 41·28 | 0·9830 | 15 2 | 39·91 | 0·9503 | 15 32 | 38·63 | 0·9197 |
| 14 33 | 41·23 | 0·9818 | 15 3 | 39·87 | 0·9492 | 15 33 | 38·59 | 0·9187 |
| 14 34 | 41·19 | 0·9807 | 15 4 | 39·82 | 0·9482 | 15 34 | 38·54 | 0·9177 |
| 14 35 | 41·14 | 0·9796 | 15 5 | 39·78 | 0·9471 | 15 35 | 38·50 | 0·9167 |
| 14 36 | 41·09 | 0·9785 | 15 6 | 39·74 | 0·9461 | 15 36 | 38·46 | 0·9158 |
| 14 37 | 41·04 | 0·9774 | 15 7 | 39·69 | 0·9450 | 15 37 | 38·42 | 0·9148 |
| 14 38 | 41·00 | 0·9762 | 15 8 | 39·65 | 0·9440 | 15 38 | 38·38 | 0·9138 |
| 14 39 | 40·96 | 0·9751 | 15 9 | 39·60 | 0·9130 | 15 39 | 38·34 | 0·9128 |
| 14 40 | 40·91 | 0·9740 | 15 16 | 39·56 | 0·9419 | 15 40 | 38·30 | 0·9119 |
| 14 41 | 40·86 | 0·9729 | 15 11 | 39·52 | 0·9409 | 15 41 | 38·26 | 0·9109 |
| 14 42 | 40·81 | 0·9718 | 15 12 | 39·47 | 0·9398 | 15 42 | 38·22 | 0·9099 |
| 14 13 | 40·77 | 0·9707 | 15 13 | 39·43 | 0·9388 | 15 43 | 38·18 | 0·9090 |
| 14 14 | 10·72 | 0·9696 | 15 14 | 39·39 | 0·9378 | 15 44 | 38·14 | 0·9080 |
| 14 45 | 40·68 | 0·9685 | 15 15 | 39·34 | 0·9368 | 15 45 | 38·10 | 0·9070 |
| 14 46 | 40·63 | 0·9674 | 15 16 | 39·30 | 0·9357 | 15 46 | 38·05 | 0·9061 |
| 14 47 | 40·59 | 0·9663 | 15 17 | 39·26 | 0·9347 | 15 47 | 38·01 | 0·9051 |
| 14 48 | 40·54 | 0·9653 | 15 18 | 39·22 | 0·9337 | 15 48 | 37·97 | 0·9042 |
| 14 49 | 40·49 | 0·9642 | 15 19 | 39·17 | 0·9327 | 15 49 | 37·93 | 0·9032 |
| 14 50 | 40·45 | 0·9631 | 15 20 | 39·13 | 0·9317 | 15 50 | 37·89 | 0·9023 |
| 14 51 | 40·40 | 0·9620 | 15 21 | 39·09 | 0·9307 | 15 51 | 37·85 | 0·9013 |
| 14 52 | 40·36 | 0·9609 | 15 22 | 39·05 | 0·9297 | 15 52 | 37·82 | 0·9004 |
| 14 53 | 40·31 | 0·9598 | 15 23 | 39·00 | 0·9286 | 15 53 | 37·78 | 0·8994 |
| 14 54 | 40·27 | 0·9588 | 15 24 | 38·96 | 0·9276 | 15 54 | 37·74 | 0·8985 |
| 14 55 | 40·22 | 0·9577 | 15 25 | 38·92 | 0·9266 | 15 55 | 37·79 | 0·8975 |
| 14 56 | 40·18 | 0·9566 | 15 26 | 38·88 | 0·9256 | 15 56 | 37·66 | 0·8966 |
| 14 57 | 40·13 | 0·9556 | 15 27 | 38·83 | 0·9246 | 15 57 | 37·62 | 0·8957 |
| 14 58 | 40·09 | 0·9545 | 15 28 | 38·79 | 0·9236 | 15 58 | 37·58 | 0·8947 |
| 14 59 | 40·04 | 0·9534 | 15 29 | 38·75 | 0·9226 | 15 59 | 37·54 | 0·8938 |

## TABLE FOR CANDLE CORRECTIONS.

*Table for Finding the Rate of Consumption of Sperm by Two Candles in Ten Minutes from Observations of the Time Required to Burn Forty Grains.*

| Time required to burn 40 Grains. | | Rate of Consumption in 10 Minutes. | Time required to burn 40 Grains. | | Rate of Consumption in 10 Minutes. |
|---|---|---|---|---|---|
| Min. | Sec. | Grains. | Min. | Sec. | Grains. |
| 9 | 0 | 44·4 | 10 | 0 | 40·0 |
| 9 | 2 | 44·2 | 10 | 2 | 39·8 |
| 9 | 4 | 44·1 | 10 | 4 | 39·7 |
| 9 | 6 | 43·9 | 10 | 6 | 39·6 |
| 9 | 8 | 43·8 | 10 | 8 | 39·4 |
| 9 | 10 | 43·6 | 10 | 10 | 39·3 |
| 9 | 12 | 43·5 | 10 | 12 | 39·2 |
| 9 | 14 | 43·3 | 10 | 14 | 39·1 |
| 9 | 16 | 43·2 | 10 | 16 | 39·0 |
| 9 | 18 | 43·0 | 10 | 18 | 38·8 |
| 9 | 20 | 42·8 | 10 | 20 | 38·7 |
| 9 | 22 | 42·7 | 10 | 22 | 38·6 |
| 9 | 24 | 42·6 | 10 | 24 | 38·4 |
| 9 | 26 | 42·4 | 10 | 26 | 38·3 |
| 9 | 28 | 42·2 | 10 | 28 | 38·2 |
| 9 | 30 | 42·1 | 10 | 30 | 38·1 |
| 9 | 32 | 42·0 | 10 | 32 | 38·0 |
| 9 | 34 | 41·8 | 10 | 34 | 37·9 |
| 9 | 36 | 41·6 | 10 | 36 | 37·7 |
| 9 | 38 | 41·5 | 10 | 38 | 37·6 |
| 9 | 40 | 41·4 | 10 | 40 | 37·5 |
| 9 | 42 | 41·2 | 10 | 42 | 37·4 |
| 9 | 44 | 41·1 | 10 | 44 | 37·2 |
| 9 | 46 | 41·0 | 10 | 46 | 37·1 |
| 9 | 48 | 40·8 | 10 | 48 | 37·0 |
| 9 | 50 | 40·7 | 10 | 50 | 36·9 |
| 9 | 52 | 40·5 | 10 | 52 | 36·8 |
| 9 | 54 | 40·4 | 10 | 54 | 36·7 |
| 9 | 56 | 40·2 | 10 | 56 | 36·6 |
| 9 | 58 | 40·1 | 10 | 58 | 36·5 |
| 10 | 0 | 40·0 | 11 | 0 | 36·4 |

## KEATES'S TABLE OF THE ILLUMINATING POWER OF SPERM LAMP,

*Calculated from the Time required to consume 200 Grains of Sperm Oil with a 2-inch Flame; 925 Grains of Oil consumed in an Hour, giving the Standard Light of 16 Sperm Candles.*

| Time required. | Value of Lamp in Sperm Candles. | Time required. | Value of Lamp in Sperm Candles. | Time required. | Value of Lamp in Sperm Candles. | Time required. | Value of Lamp in Sperm Candles. | Time required. | Value of Lamp in Sperm Candles. |
|---|---|---|---|---|---|---|---|---|---|
| Min. Sec. | | Min. Sec. | | Min. Sec. | | Min. Sec. | | Min. Sec. | |
| 11 0 | 18·86 | 11 38 | 17·83 | 12 15 | 16·94 | 12 52 | 16·12 | 13 29 | 15·39 |
| 11 1 | 18·83 | 11 39 | 17·81 | 12 16 | 16·91 | 12 53 | 16·10 | 13 30 | 15·37 |
| 11 2 | 18·80 | 11 40 | 17·78 | 12 17 | 16·89 | 12 54 | 16·08 | 13 31 | 15·34 |
| 11 3 | 18·77 | 11 41 | 17·75 | 12 18 | 16·87 | 12 55 | 16·06 | 13 32 | 15·33 |
| 11 4 | 18·73 | 11 42 | 17·73 | 12 19 | 16·84 | 12 56 | 16·04 | 13 33 | 15·31 |
| 11 5 | 18·71 | 11 43 | 17·71 | 12 20 | 16·82 | 12 57 | 16·02 | 13 34 | 15·29 |
| 11 6 | 18·68 | 11 44 | 17·68 | 12 21 | 16·80 | **12 58** | **16·00** | 13 35 | 15·27 |
| 11 7 | 18·66 | 11 45 | 17·66 | 12 22 | 16·77 | 12 59 | 15·98 | 13 36 | 15·25 |
| 11 8 | 18·63 | 11 46 | 17·63 | 12 23 | 16·75 | 13 0 | 15·96 | 13 37 | 15·24 |
| 11 9 | 18·61 | 11 47 | 17·60 | 12 24 | 16·73 | 13 1 | 15·94 | 13 38 | 15·22 |
| 11 10 | 18·58 | 11 48 | 17·58 | 12 25 | 16·70 | 13 2 | 15·92 | 13 39 | 15·20 |
| 11 11 | 18·55 | 11 49 | 17·56 | 12 26 | 16·68 | 13 3 | 15·90 | 13 40 | 15·18 |
| 11 12 | 18·53 | 11 50 | 17·54 | 12 27 | 16·66 | 13 4 | 15·88 | 13 41 | 15·16 |
| 11 13 | 18·50 | 11 51 | 17·51 | 12 28 | 16·64 | 13 5 | 15·86 | 13 42 | 15·15 |
| 11 14 | 18·47 | 11 52 | 17·48 | 12 29 | 16·62 | 13 6 | 15·84 | 13 43 | 15·13 |
| 11 15 | 18·44 | 11 53 | 17·46 | 12 30 | 16·60 | 13 7 | 15·82 | 13 44 | 15·10 |
| 11 16 | 18·42 | 11 54 | 17·44 | 12 31 | 16·58 | 13 8 | 15·80 | 13 45 | 15·09 |
| 11 17 | 18·39 | 11 55 | 17·41 | 12 32 | 16·55 | 13 9 | 15·77 | 13 46 | 15·07 |
| 11 18 | 18·37 | 11 56 | 17·39 | 12 33 | 16·52 | 13 10 | 15·75 | 13 47 | 15·05 |
| 11 19 | 18·34 | 11 57 | 17·36 | 12 34 | 16·50 | 13 11 | 15·73 | 13 48 | 15·03 |
| 11 20 | 18·31 | 11 58 | 17·34 | 12 35 | 16·48 | 13 12 | 15·72 | 13 49 | 15·01 |
| 11 21 | 18·28 | 11 59 | 17·31 | 12 36 | 16·46 | 13 13 | 15·70 | 13 50 | 15·00 |
| 11 22 | 18·25 | 12 0 | 17·29 | 12 37 | 16·44 | 13 14 | 15·68 | 13 51 | 14·98 |
| 11 23 | 18·22 | 12 1 | 17·26 | 12 38 | 16·42 | 13 15 | 15·66 | 13 52 | 14·96 |
| 11 24 | 18·20 | 12 2 | 17·24 | 12 39 | 16·40 | 13 16 | 15·64 | 13 53 | 14·94 |
| 11 25 | 18·17 | 12 3 | 17·22 | 12 40 | 16·38 | 13 17 | 15·62 | 13 54 | 14·92 |
| 11 26 | 18·15 | 12 6 | 17·20 | 12 41 | 16·36 | 13 18 | 15·60 | 13 55 | 14·90 |
| 11 27 | 18·12 | 12 4 | 17·17 | 12 42 | 16·34 | 13 19 | 15·58 | 13 56 | 14·89 |
| 11 28 | 18·10 | 12 5 | 17·14 | 12 43 | 16·32 | 13 20 | 15·56 | 13 57 | 14·87 |
| 11 29 | 18·07 | 12 7 | 17·12 | 12 44 | 16·30 | 13 21 | 15·54 | 13 58 | 14·85 |
| 11 30 | 18·04 | 12 8 | 17·10 | 12 45 | 16·28 | 13 22 | 15·52 | 13 59 | 14·84 |
| 11 31 | 18·02 | 12 9 | 17·08 | 12 46 | 16·25 | 13 23 | 15·50 | 14 0 | 14·82 |
| 11 32 | 17·99 | 12 10 | 17·05 | 12 47 | 16·23 | 13 24 | 15·48 | 14 1 | 14·80 |
| 11 33 | 17·97 | 12 11 | 17·02 | 12 48 | 16·21 | 13 25 | 15·46 | 14 2 | 14·78 |
| 11 34 | 17·94 | **12 12** | **17·00** | 12 49 | 16·19 | 13 26 | 15·44 | 14 3 | 14·76 |
| 11 35 | 17·92 | 12 13 | 16·98 | 12 50 | 16·17 | 13 27 | 15·42 | 14 4 | 14·75 |
| 11 36 | 17·88 | 12 14 | 16·96 | 12 51 | 16·15 | 13 28 | 15·40 | 14 5 | 14·73 |
| 11 37 | 17·86 | | | | | | | | |

# INDEX.

11/21/1899 METER = 505 IN 10 MIN.

CANDLES = 10.22 = 38.6 - RATE 10 MIN.

11.8
11.3
11.4 ✓
11.3
11.4 ✓
11.5
11.5
11.6 ✓
11.8

11.50

$$\begin{array}{r} 11.50 \\ 386 \\ \hline 20\,)\,443.900 \\ 221.950 \end{array}$$

$$\frac{221.950}{.939} = 2362$$

$$\frac{2362 \times 500}{505} = 23.38 \text{ CP.}$$

YOUNG

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11/21/1899 CANDLES = 6 SEC. LATE.

METER = 592 SEC -

CANDLES = 626 SECS. 40 grs.

11.2
11.3
11.3 ✓
11.2
11.4
11.5 ✓
11.8.
11.9
12.0 ✓
11.6

11.52

$$11.52 \times \frac{592}{600} \times \frac{600}{626} \times \frac{1}{.939} \times 2 = 23.20$$

WADE.